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THE HISTORY, DEVELOPMENT, AND PERFORMANCE OF ASPHALT RUBBER AT ADOT

Special Report

Final Report

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16. Abstract (21 lines including this one - delete this comment)

This report evaluates ADOT's two decades of experience with asphalt-rubber materials. It discusses the chronological development of asphalt rubber by ADOT and the five principle uses of asphalt rubber. The performance of asphalt-rubber materials are determined from historical records and pavement test sections.

The performance of asphalt rubber is evaluated by utilizing historical data from ADOT's pavement management system database and by reviewing eight experimental projects which included 47 test sections. Pavement condition distress surveys were performed on several of these projects to determine the terminal condition of the pavements.

Asphalt-rubber materials have been placed on over 700 miles of roadway on the State system. This is approximately ten percent of ADOT's highway network. Although regularly used on the Interstate System, the principle use has occurred on State and U.S. Routes. The major application has been in mitigating reflective cracking with over 90% of the applications consisting of SAMs and SAMIs.

The average life of a SAM is approximately five years on the Interstate and ten years and eight years for the State and U.S. Routes, respectively. The coefficient of variation in service life ranges between 30%-40% for all three highway classifications. The average life of a SAMI is approximately nine years for both the Interstate and State Routes while it is only three years on the U.S. Routes.

Asphalt rubber has successfully been used as an encapsulating membrane to control pavement distortion due to expansive soils and to reduce reflection cracking in overlays on both rigid and flexible pavements.

During the twenty years of asphalt rubber use, ADOT has evolved from using slurry applied asphalt-rubber chip seals to utilizing reacted asphalt rubber as a binder in open and dense graded asphalt concrete.

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INTRODUCTION

The ADOT has used asphalt-rubber materials in the construction and preservation of pavements since the mid 1960s. Through the last twenty years many field experiments have been conducted and changes made in materials, specifications, and design philosophies. This paper discusses ADOT's experience with asphalt-rubber materials and the current use and state of the practice.

Asphalt-rubber materials have been placed on approximately 700 miles of roadway on the State System. This is approximately ten percent of ADOT's highway network. Although regularly used on the Interstate System, the principal use of asphalt rubber has occurred on State Routes and U. S. Routes. The major application has been in mitigating reflective cracking with over 90% of the applications consisting of stress absorbing membranes (SAMs) and stress absorbing membrane interlayers (SAMIs).

ADOT has successfully utilized asphalt rubber for five different applications: as a pavement membrane to prevent reflective cracking in overlays placed upon both flexible and rigid pavements; as a subgrade/pavement membrane to mitigate differential movements induced by expansive soils; as a sealant for cracks in asphalt concrete pavements and joints in concrete pavements; as an economical design strategy for low volume roads; and as a membrane to prevent moisture intrusion into bridge decks.[1] The relative percentage of use for each of these applications is shown in Figure 1. The percentages are based upon roadway miles at placement. No information is presented for crack and joint sealants since this information was not readily available at the time of this paper. The use of asphalt rubber for crack/joint sealing and as a membrane for bridge decks is not discussed in this paper.

HISTORICAL DEVELOPMENT

Introduction

The development of asphalt rubber by ADOT paralleled the work of Charles McDonald of the City of Phoenix. The first McDonald "band aid" test patch utilized by ADOT was applied on U. S. 666 in 1964.[2] Except for one experimentation in 1967, no other field testing was conducted by ADOT until 1968. During that time the industry evolved from hand placement of McDonald "band aid" sections to mass application of asphalt rubber using a slurry machine. Although considerably more efficient, layer thickness control was difficult due to surface irregularities such as wheel ruts where an excess amount of asphalt rubber resulted.

In 1968, ADOT placed its first asphalt-rubber surface application with a distributor truck. That marked the beginning of a new era for ADOT. With the ability to use distributor trucks to dispense asphalt rubber, the industry acquired a means for producing a quality product at an economical cost. Over the next four years, ADOT developed its asphalt-rubber specifications and construction techniques through field testing and utilization of industry standards.

The only application for asphalt rubber was as a binder for chip seals (SAM) and there was only one supplier, Sahuaro Petroleum and Asphalt Company. Rubber particles were typically vulcanized rubber supplied by Atlos Rubber Company ranging in size between the #16 and #25 sieve size.

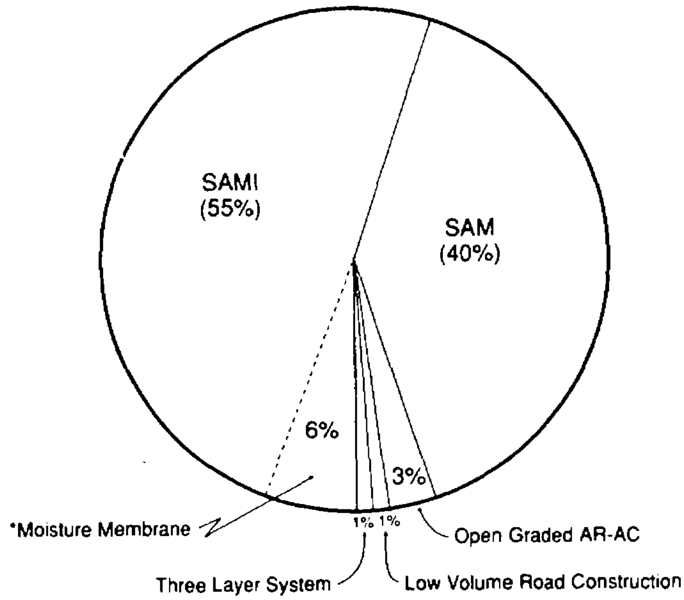

Figure 1 - Distribution of Asphalt-Rubber Use by Application

SAM Development

Between 1968-1972 ADOT incorporated asphalt rubber on six construction projects. During this time several improvements were developed. Most notable was the use of kerosene to lower the viscosity of the asphalt-rubber mixture just prior to dispensing (1972), the need to overlap longitudinal joints and utilize sand blotter (1972), and the change from penetration grade asphalts to AR graded asphalts (1972-73).

Although numerous field trials were made to vary binder content, mineral aggregate gradation, mineral aggregate voidage, and layer position within the pavement structure, ADOT has generally used the same specifications for all asphalt-rubber mixtures. They typically consisted of asphalt rubber proportioned 75% asphalt to 25% rubber, mixed at elevated temperatures (350°+ F), diluted with kerosene just prior to application (5%-7%), and spray applied at 0.6 gallons/yard^2. CM-11 cover material was rolled into the membrane after placement.

In 1975, Arizona Refining Company (ARCO) developed an asphalt-rubber mixture to compete with the Sahuaro process. This new mixture differed in that it used devulcanized rubber, was proportioned 80:20, and utilized extender oil in lieu of kerosene. Once suitable specifications were developed for the ARCO process (approximately 1976), they remained essentially unchanged.

SAMI Development

ADOT placed its first stress absorbing membrane interlayer (SAMI) in 1972 on I-40 when 18 test sections were constructed in conjunction with the Federal NEEP Project No. 10 - Reducing Reflective Cracking in Bituminous Overlays.[3] The interlayer was situated above the overlay and beneath the ACFC wearing course. The next SAMI installation occurred in 1975, also on I-40, when an encapsulating membrane was placed over the existing pavement and cut ditches prior to overlay placement. Although situating the SAMI beneath the overlay is believed to have been a result of accommodating the cut ditch sealing, this was a fortunate installation. Research in the near future would indicate that positioning an interlayer upon the existing pavement would maximize its benefit.[4] Most future SAMI applications were placed upon a leveling course and beneath the overlay. The leveling course was used to provide a smooth platform upon which to place the SAMI and subsequent overlay. The leveling course also prevented puddling of the asphalt rubber in depressions in the existing pavement.

Three Layer System Development

ADOT first began experimenting with ways of overlaying old concrete pavements with asphalt-rubber membranes in 1973. They participated in a joint effort with the City of Phoenix to construct a test section on Madison Avenue. Although only a two layer system, this was the beginning of the three layer development (See Figure 2)[5]. The next experiment occurred in 1974 on I-17 near Bell Road. Again this was a two layer system with a CM-11 chip applied to the final surface. Due to the high traffic volumes and speeds encountered on I-17, considerable windshield damage occurred. This problem led to the need for a third layer such as an ACFC to prevent windshield damage. However, concern did exist as to whether the third layer was constructible and whether it would shove and rut under traffic. To verify its constructibility and performance, a test section was placed in 1975 on State Route 87 on an asphalt concrete pavement. The success of this project led to additional installations as shown in Figure 2. During 1976-77 additional experimental sections were placed to study the effects of application rates, void size in leveling course, and vulcanized versus devulcanized rubber. In 1985, the first use of the three layer system as a non experimental design occurred when it again was placed on I-17 to restore ride and prevent reflection cracking.

Moisture Membrane Development

The first use of an asphalt-rubber membrane to control differential movement due to expansive soils was in 1973. A catalytically-blown asphalt membrane was placed upon the subgrade prior to placement of the select material and asphalt concrete. Although this treatment worked well it was recognized that most of the roadways within the distribution of expansive soils had already been constructed. Therefore, the membrane could only be placed at the subgrade level during reconstruction. To alleviate this problem ADOT constructed four projects between 1974 and 1976 to verify the effectiveness of a membrane placed over the existing pavements and shoulders. The favorable performance of these tests resulted in ADOT utilizing the "encapsulating membrane concept" as a standard design strategy. Approximately 10-20 projects have utilized this technique.

Asphalt Rubber as a Low Volume Road Design Strategy

Only one experimental project has evaluated this strategy. The experimental project was constructed in 1977 on State Route 169 and consisted of four different design strategies incorporating asphalt rubber. Although two of the six sections placed performed satisfactorily, little or no additional use of this technique has occurred.

Rubber Manufacturers

Since the beginning of ADOT's involvement with asphalt rubber, two manufacturers dominated the rubber supply market. Most rubber for the McDonald/Sahuaro process consisted of vulcanized rubber (TP044) from Atlos Rubber Company. Once the ARCO process became competitive, devulcanized rubber was utilized in this process which was generally obtained from the U. S. Rubber Reclaiming Company.

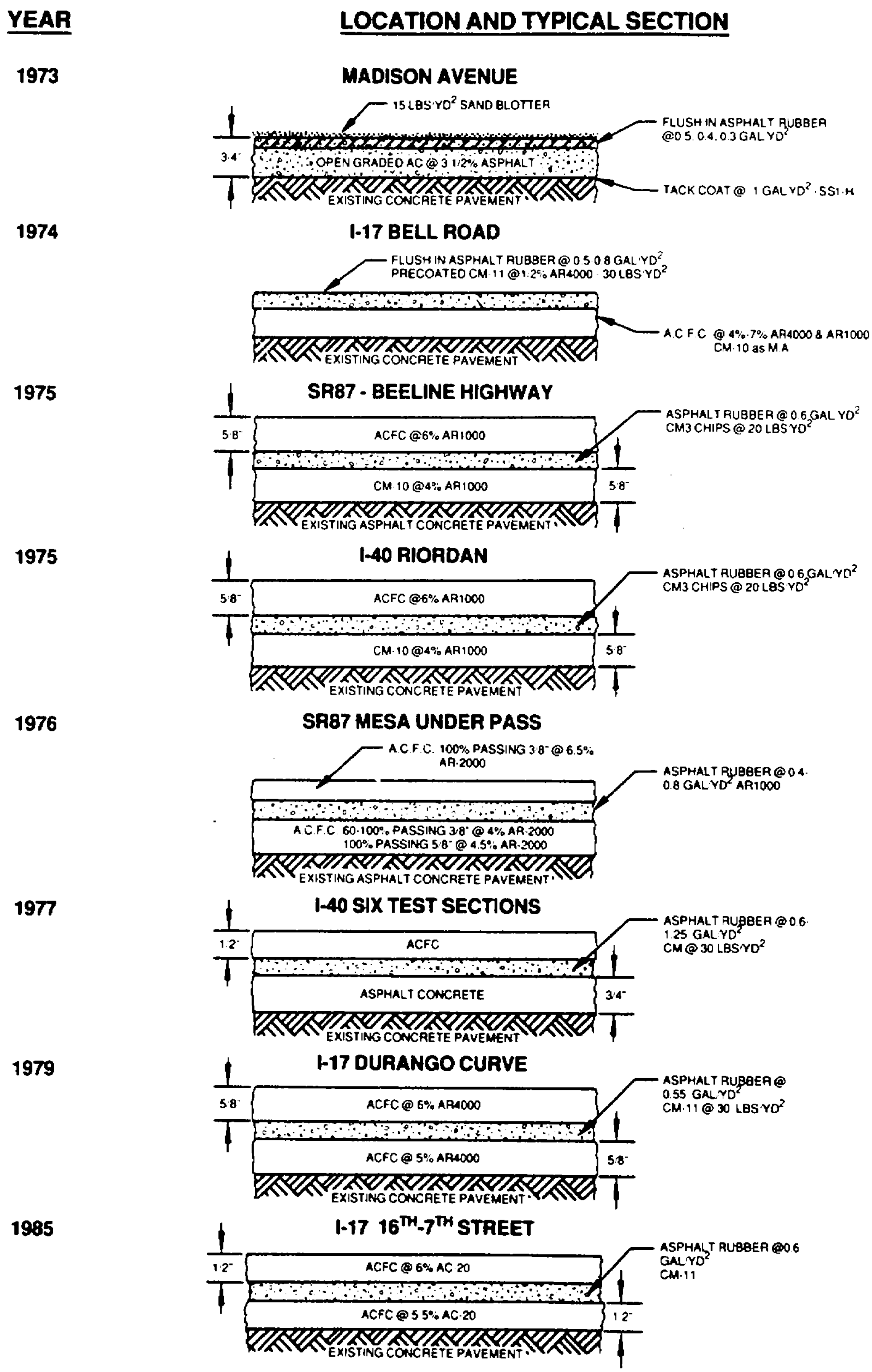

Figure 2 - Typical Sections of Three Layer Projects

Asphalt-Rubber Asphalt Concrete Mixture Development

Reacted asphalt rubber was first used as a binder in an open-graded asphalt concrete mixture in 1975. Two test sections were incorporated into an experimental section on State Route 87 to evaluate the effectiveness of this treatment. In 1978, three additional test sections were constructed on the Buckeye-Liberty experimental project. The open-graded mixtures with asphalt-rubber binder were used as a design strategy on a limited basis between 1977 and 1981. The first use of a dense graded asphalt-rubber asphalt concrete occurred in 1986 when a detour was constructed on I-40 using this material. More recently (1987), a 3/4 inch lift of open graded asphalt-rubber asphalt concrete was placed on I-19 as an overlay to restore ride to a concrete pavement. In October of 1989 a one inch thick asphalt-rubber ACFC was placed as an overlay on I-17 near Camp Verde, Arizona.

ADOT Use of Asphalt Rubber

The chronological development of asphalt-rubber applications by ADOT is shown in Figure 3. It should be noted that the development of asphalt-rubber applications began with chip seals (SAM), then evolved into SAMIs, and finally into the three layer system. At the time ADOT placed the first true three layer system (1975) they also placed the first open-graded asphalt concrete with an asphalt-rubber binder. This marked the beginning of the development of an open-graded asphalt concrete utilizing asphalt rubber as a binder. This development has continued on a sporadic basis until the present time.

Development of the various applications occurred through field testing only. The laboratory investigations into the mixture properties of asphalt rubber did not occur on a major scale until all the design applications had been field tested.

The number of roadway miles of asphalt rubber placed in each year for each application is shown in Figures 4 through 7. It is evident that the greatest application of SAMs was durring 1975-1976 while the greatest application of SAMIs occurred during 1976-1977. The mid 1970s was a milestone in the use of asphalt rubber by ADOT. During this era, the most field testing and construction applications occurred.

The asphalt-rubber project locations are shown in Figure 8 along with the locations of the experimental projects.

NETWORK LEVEL FIELD PERFORMANCE OF ASPHALT-RUBBER SECTIONS

Introduction

ADOT has been collecting network level pavement distress data since 1972. A pavement management system has been operational since 1980 and includes distress measurements for each milepost location on ADOT's 7369 centerline miles of roadway. Pavement distress measurements are currently recorded for roughness, skid, cracking, rutting, flushing, patching, and faulting. Historical records do not include all these distresses.

The performance of the asphalt-rubber applications can be assessed utilizing network level Pavement Management System (PMS) data. This was satisfactorily demonstrated in a previous study.[6] Utilizing PMS data it is possible to determine the useful service life of the various strategies and also to gain insight as to the agencies philosophies for the use of asphalt rubber. Specifically, the types of roadways the strategy is employed on, i.e. Interstate, State Route, etc., and the condition and age of the existing pavements prior to the rehabilitation.

When utilizing PMS data for network level pavement performance evaluations, several important points should be remembered. The performance of any given section is not solely a function of the treatment itself. It is also a function of the existing condition of the roadway prior to rehabilitation, the judicious selection of the design engineer in choosing the most appropriate treatment, the contractors and inspectors abilities to produce a quality product, and the maintenance authority's abilities to properly maintain the roadway. All these aspects should be considered when assessing performance in terms of PMS data.

Furthermore, the Interstate System is maintained at a higher serviceability (PSI>3.0) than the State and U.S. Routes. Therefore, the time until rehabilitation would be different between these functional classifications even if the pavement deterioration were the same.

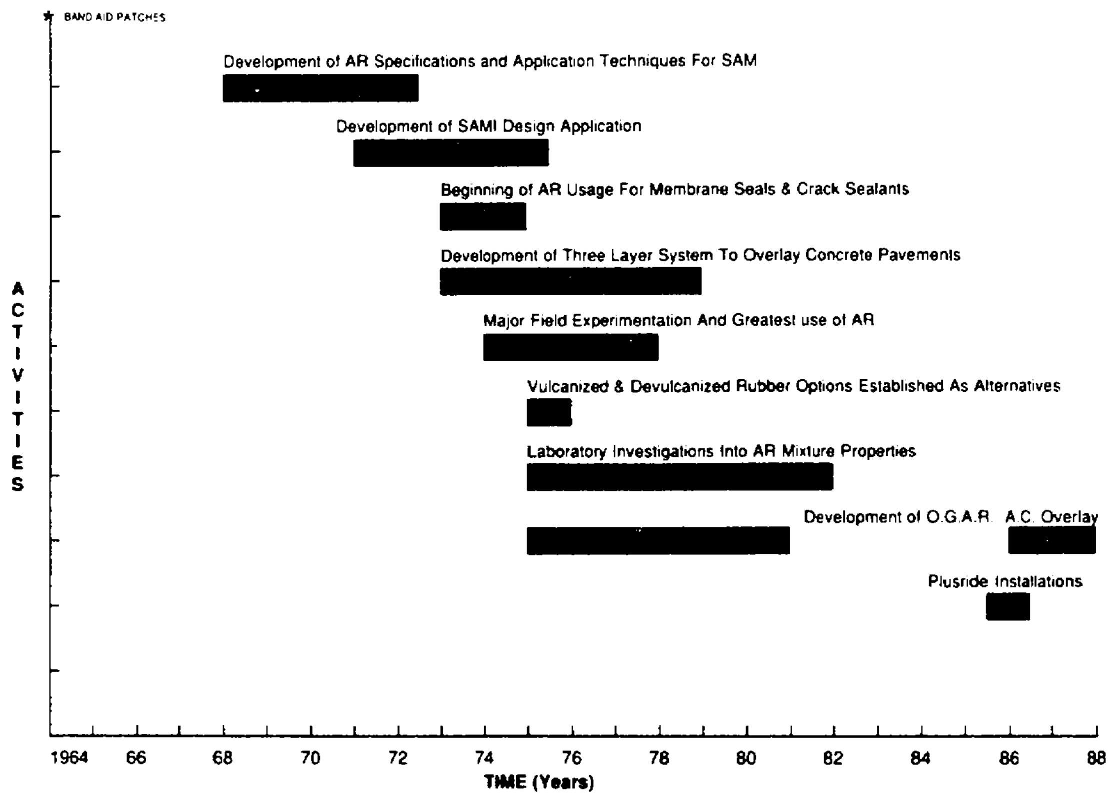

Figure 3 - Chronology of Asphalt-Rubber Development in ADOT

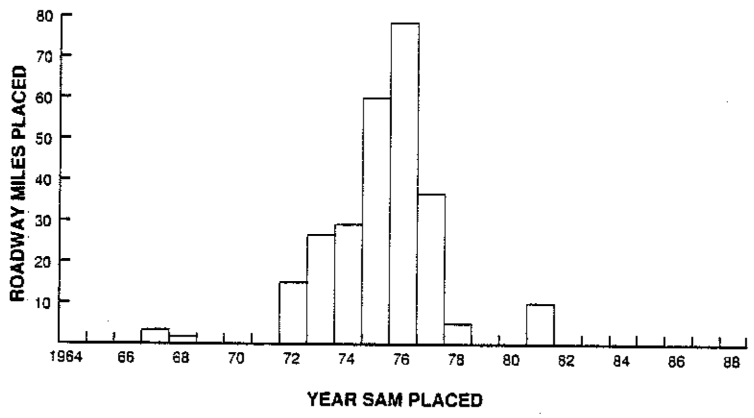

Figure 4 - Roadway Miles of SAM Placed By Year

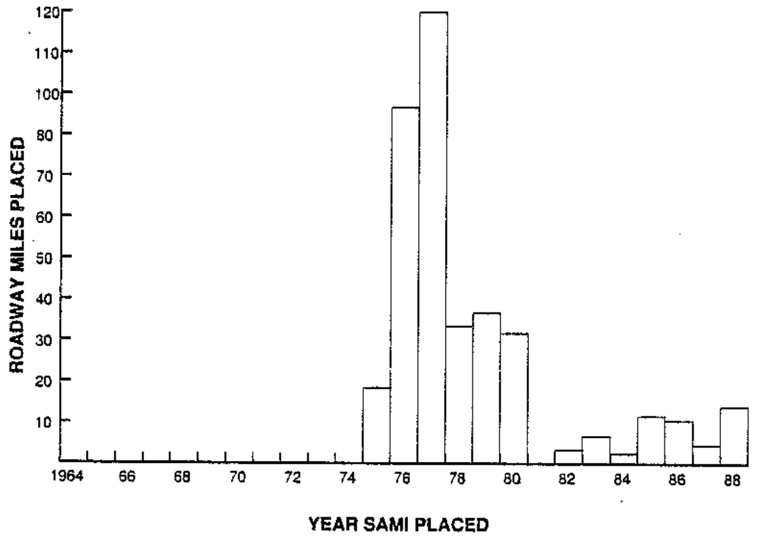

Figure 5 - Roadway Miles of SAMI Placed By Year

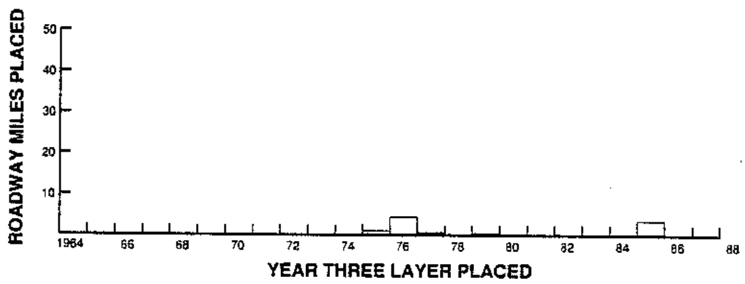

Figure 6 - Roadway Miles of Three Layer System Placed By Year

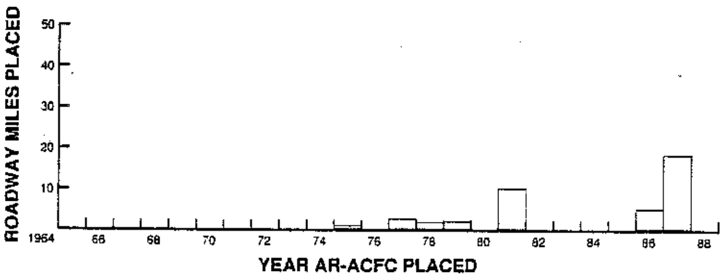

Figure 7 - Roadway Miles of AR-ACFC Placed By Year

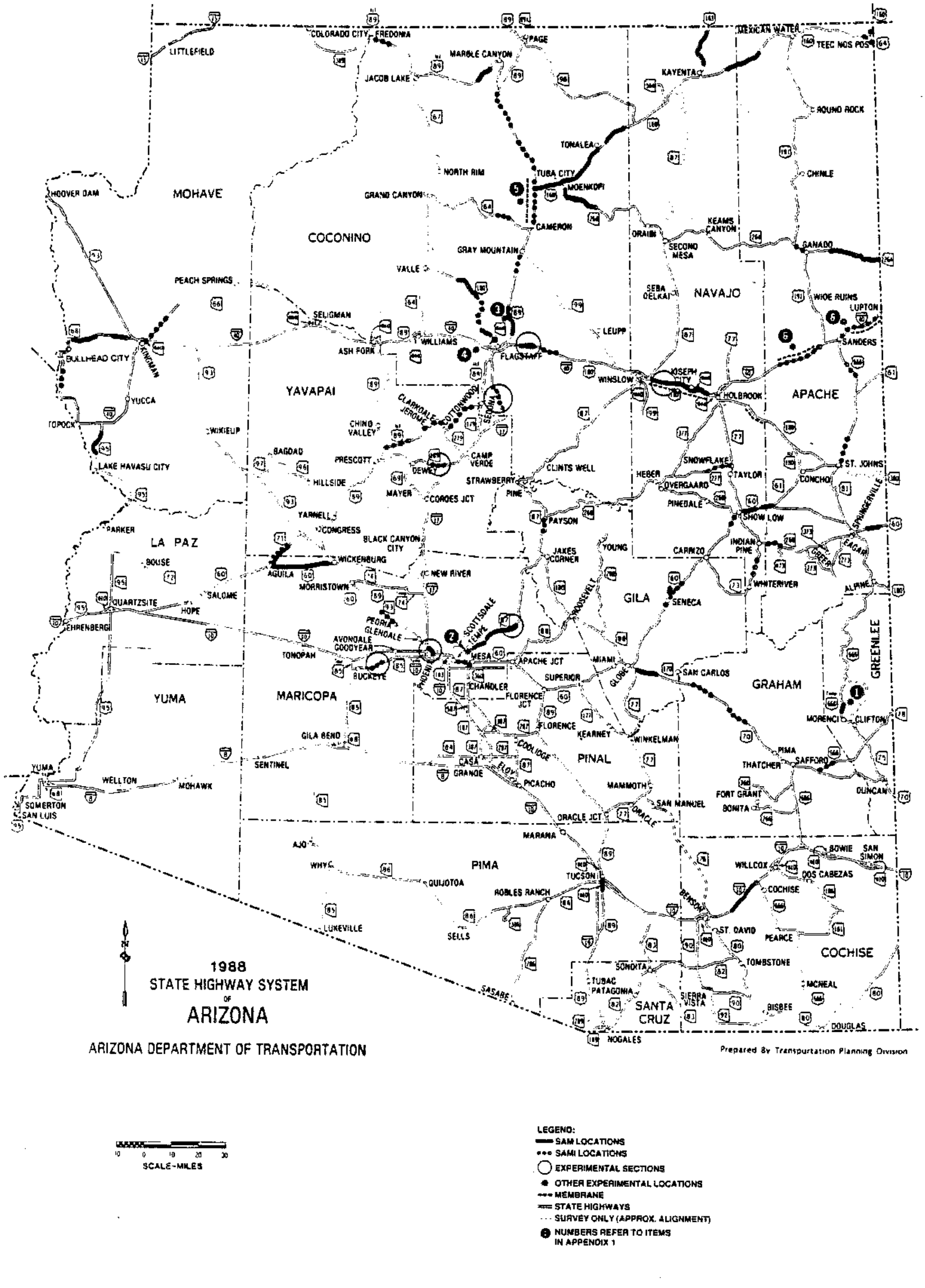

Figure 8 - Asphalt Rubber Project Locations

The use of asphalt rubber did not evolve as a preventative maintenance treatment, instead its use was limited to badly deteriorated pavements where reflective cracking was a concern. In 1975, ADOT initiated a policy which required the use of a SAMI on all projects where overlays of less than four inches were to be placed over badly cracked pavements (>10% cracking)[7]. Therefore, comparisons to other strategies which did not include rubber are difficult since they would not have been utilized on as badly deteriorated pavements.

Performance of SAMs

Pavement survival curves were developed utilizing the PMS data through 1988. These curves represent the pavement life from the time the SAM was placed until the next major treatment occurred such as a seal coat or overlay. Figure 9 displays these curves for three roadway classifications; Interstate, State Route, and U. S. Route. Figure 10 displays the pavement age curves which indicate the existing pavement age distribution for each of the roadway classifications at the time of SAM placement.

It is evident that the performance of SAMs on the Interstate is significantly different than either the State or U. S. Routes. This is not surprising since the Interstate receives approximately ten times the loadings as shown in Table 1. The marked difference in the position of the survival curves for the U. S. and State Routes is surprising since both have similar loading levels (see Table 1). However, upon inspection of the age distribution curves it becomes clear that the U. S. routes were significantly older at the time of SAM placement. Approximately 40% of these pavements were older than 22 years at the time of the SAM treatment.

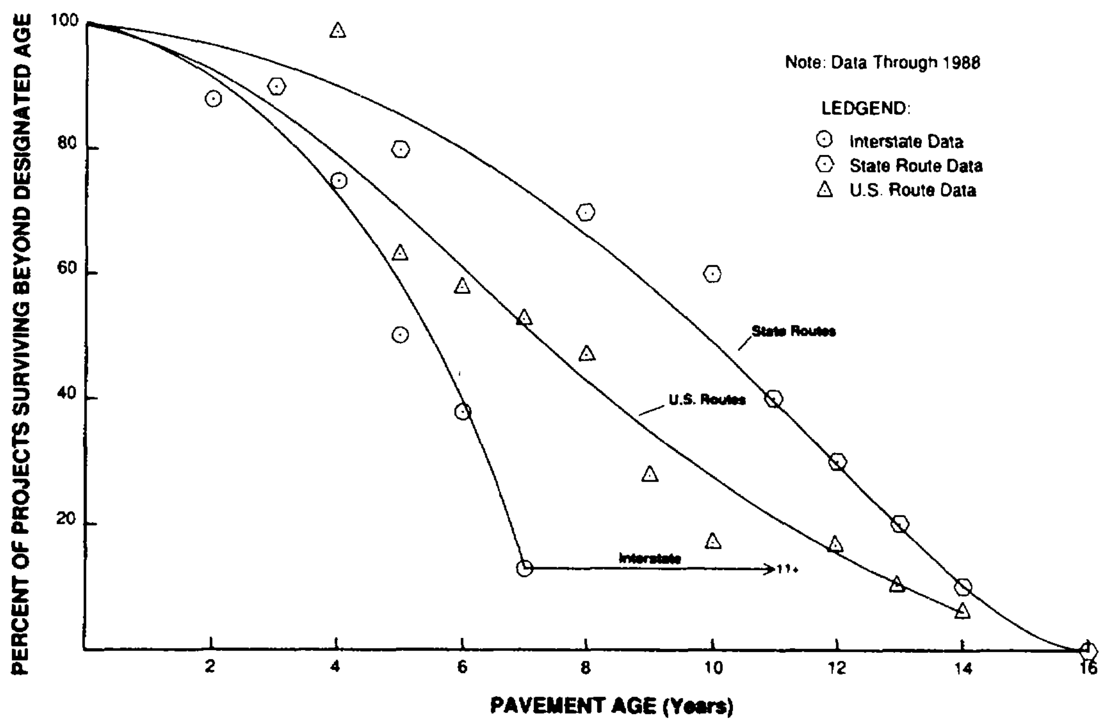

Figure 9 - Pavement Survival Curves for SAM Surface Treatments

TABLE 1 - PERFORMANCE DATA FOR SAM

Route	SAM LIFE (Years)				Pavement Age @ SAM Placement (Years)				Mean 18K ESALS* Since SAM Placement
	$\bar{X}$	σ	C.V.	R	$\bar{X}$	σ	C.V.	R	
Interstate	5.3	1.7	31%	2-7	11.6	2.7	23%	8-17	3944
State Route	10.0	3.8	38%	3-15	17.9	8.0	45%	2-29	401
U.S. Route	8.2	3.2	38%	4-13	23.4	9.7	41%	16-48	496

* Through 1985[6]

In Figure 10, it is interesting to note that a distinct linear range exists in each of the curves for the three roadway classifications.

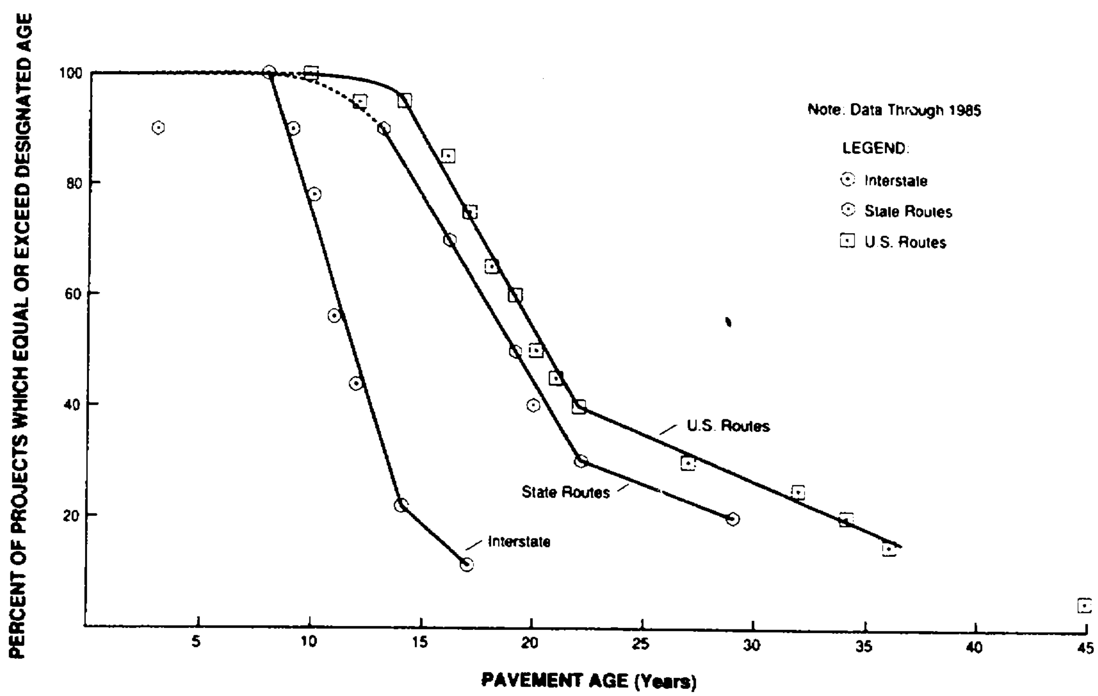

Figure 10 - Distribution of Existing Pavement Age At the Time of SAM Placement

The average time from when a SAM is placed until the first major surface treatment occurs is approximately five years on the Interstate and almost twice that on the State Routes and U. S. Routes. The coefficient of variation is similar for all three classifications, ranging between 30% and 40%.

The development of cracking on the Interstate also appears to occur at a different rate than for the other routes as shown in Figure 11. While cracking is randomly distributed around the mean for both the State and U.S. Routes, there is a slight rate of increase to the Interstate data. The resulting linear equation for the Interstate data only had an $R^2=0.32$. As would be expected the U.S. Routes exhibited higher mean cracking than the State Routes. This is presumably due to the higher age of the underlying pavements.

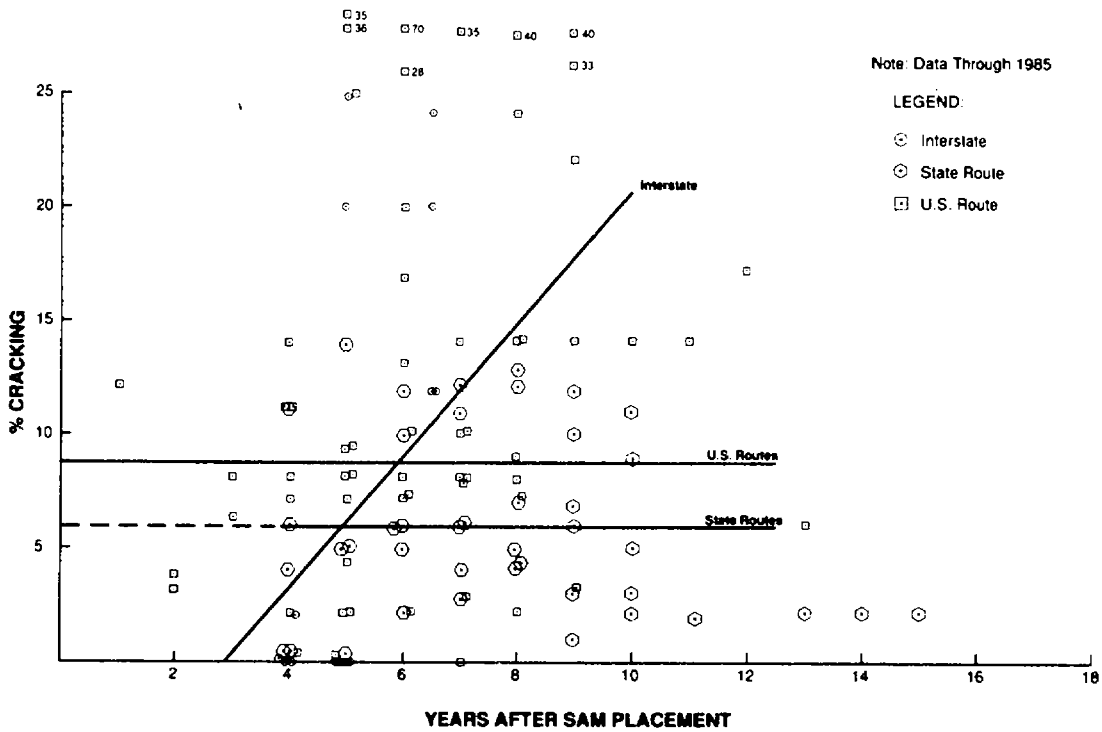

Figure 11 - Pavement Crack Development in SAMs

The rate of roughness increase was previously investigated and the findings restated in Table 2.[6] The rate of roughness increase is similar for both the Interstate and State Routes. The U.S. Routes exhibited a 13% higher rate of increase. This could possibly be a result of less maintenance on these routes and/or due to the older underlying pavements.

TABLE 2 - RATE OF ROUGHNESS INCREASE FOR SAMS[6]

Route	Mays Roughness (inches/mile/year)
Interstate	12.5
State Route	12.7
U.S. Route	14.3

Performance of SAMIs

Pavement survival curves were developed utilizing the PMS database for data through 1988. These curves represent the, pavement life from the time the SAMI was placed until the next major treatment occurred such as a seal coat or overlay. Figure 12 displays the curves for the three road classifications; Interstate, State Routes, and U. S. Routes. Figure 13 displays the pavement age curves which indicate the existing pavement age distribution for each of the roadway classifications at the time of SAMI placement.

Surprisingly, SAMIs appear to last longer on the Interstate than on the State Routes or U. S. Routes. This is probably due to the fact that Interstate pavements were in better condition at the time of SAMI placement and received approximately twice the overlay thickness (4 inches). Although, Table 3 indicates that State Routes have a slightly higher mean (9.5 years), examination of Figure 12 indicates that two of the seven data points for the State Routes appear to be outliers. For this reason, no curve is shown to represent the "survival curve." The paucity of data precludes satisfactory interpretation. The Interstate pavements have received approximately 10 times the loadings that the State or U. S. Routes received. The coefficient of variation for SAMI life for all classifications was between 41% and 45%, a significant performance variability.

TABLE 3 - PERFORMANCE DATA FOR SAMI

Route	Mean SAMI Life (Years)				Mean Overlay Thickness @ SAMI (inches)	Pavement Age @ SAMI (years)		Mean 18K ESALS* Since SAMI Application
	σ	C.V.	$\bar{X}$	R		$\bar{X}$	R	
Interstate	3.9	44	9	5-15	4.0	14	8-29	2676
State Route	3.9	41	9.5	3-13	2.0	19	9-32	241
U.S. Route	3.6	45	7.8	6-12	2.5	28	10-44	227

Figure 14 indicates the extent of cracking for each classification with time. It should be noted that all the data are not shown since most of the data would have plotted on the abscissa. The data were randomly distributed about the mean for each of the classifications. The mean was approximately 1% cracking or less for up to 10 years of service for all classifications.

The rate of increase in roughness was previously investigated and the results restated in Table 4.[6] The data analyzed for the analysis had considerable variance and therefore sections with $R^2 >= 0.70$ were utilized to determine the values shown in Table 4. The findings suggest that the State Routes have significantly lower rates of roughness increase. However, only 30% of the data were used to establish this value due to the variability in the remaining data. These findings should therefore be viewed with caution.

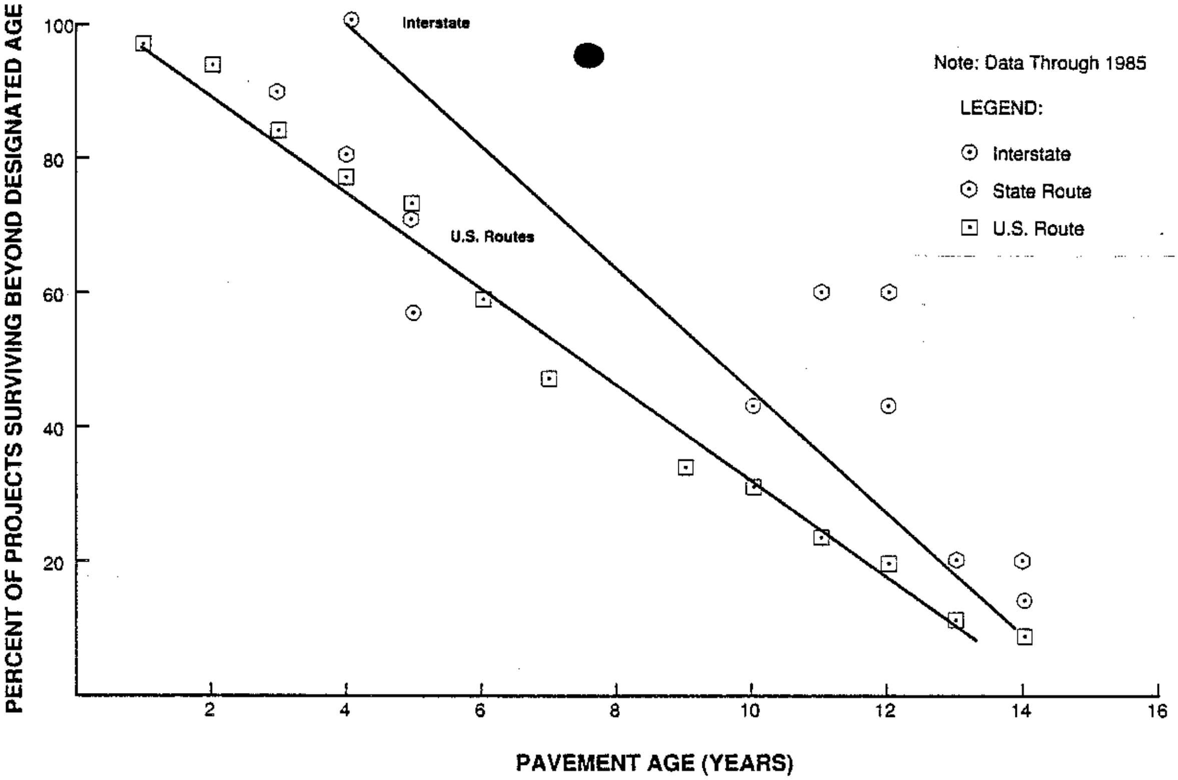

Figure 12 - Pavement Survival Curves After SAMI Application

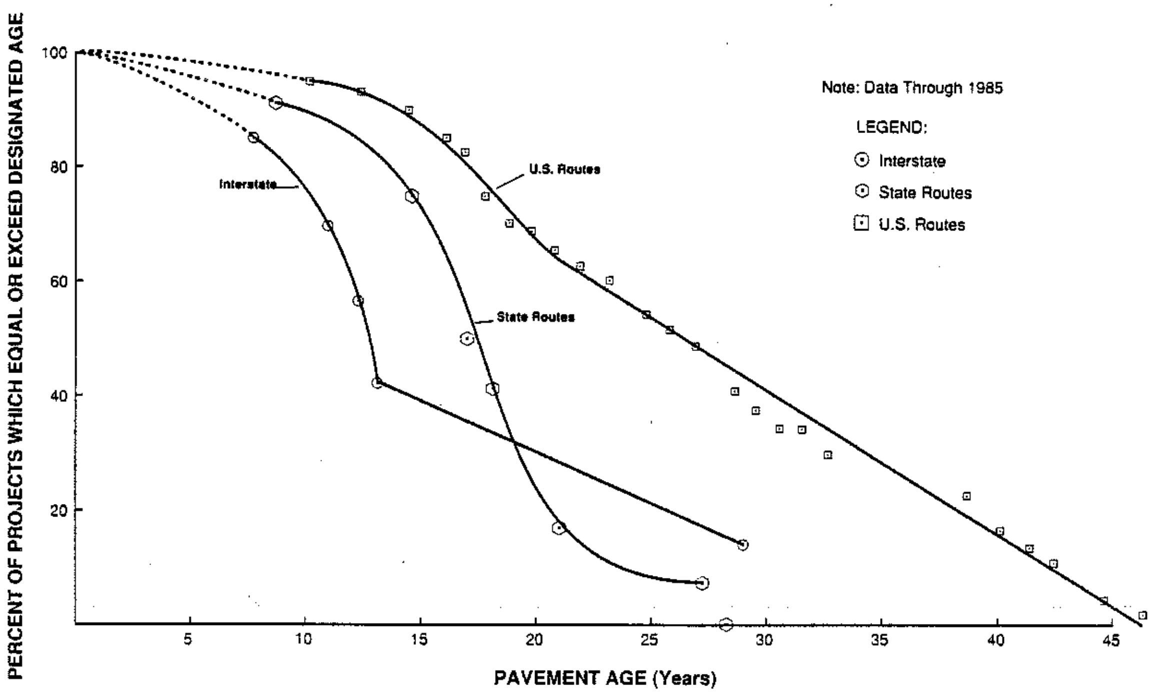

Figure 13 - Distribution of Pavement Ages of SAMI Applications

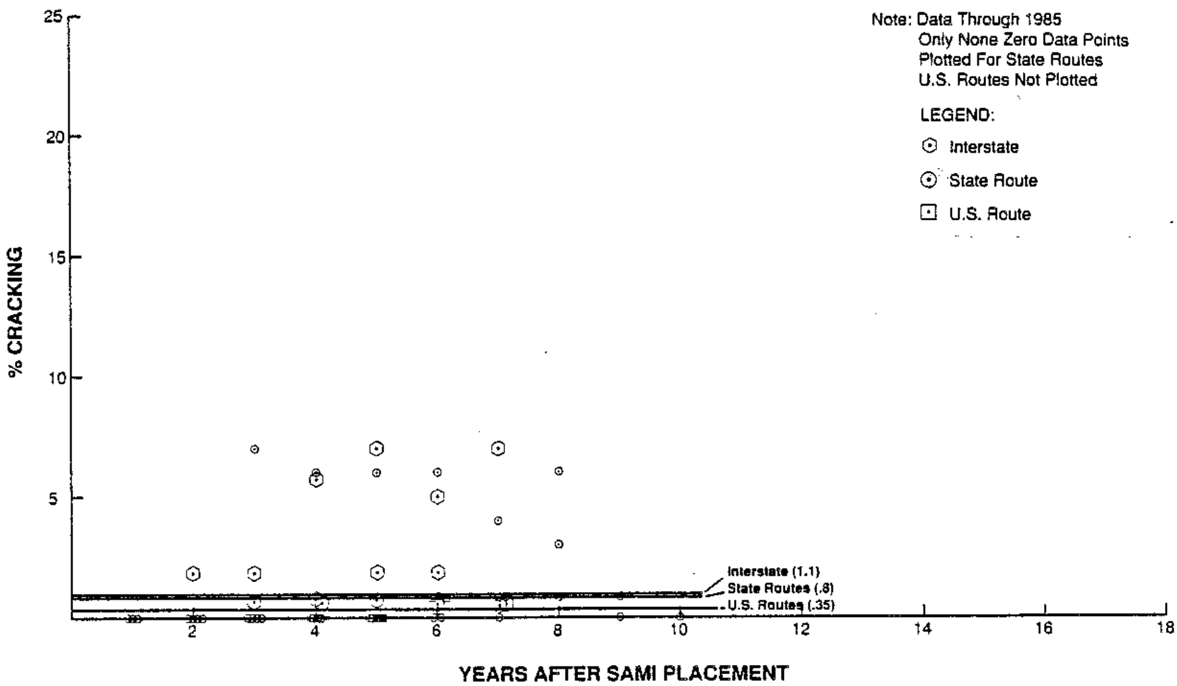

Figure 14 - Pavement Crack Development in SAMIs

TABLE 4 - RATE OF ROUGHNESS INCREASE FOR SAMI[6]

Route	Mays Roughness (inches/mile/year)
Interstate	8.9
State Route	7.0
U.S. Route	12.2

In a previous study, ADOT's PMS database was searched to locate projects which could be compared to measure the effectiveness of a SAMI treatment.[6] Three locations were found with similar construction dates and traffic loading conditions which contained contiguous SAMI and non SAMI sections. Paver distress surveys were performed on these sections in 1987 and the mean P.C.I. scores and standard deviations reprinted in Table 5.

From these comparisons, it is evident that the SAMI section on US 666 has performed equally to the "control" overlay which is almost twice its thickness. Both sections are approximately ten years old. After 8 years in service the SAMI section on US 60 is performing slightly better than the overlay (control) section of equal thickness. Both the control and SAMI sections on US 89 had a P.C.I. rating of 100. However, these sections are only 2-3 years in age and a comparison may be premature.

TABLE 5 - 1987 DISTRESS SURVEY RESULTS[6]

Route U.S. 666				Route U.S. 60				Route U.S. 89			
SAMI		CONTROL		SAMI		CONTROL		SAMI		CONTROL	
2.5 inch overlay		4.5 inch overlay		1.5 inch overlay		1.5 inch overlay		1.5 inch* overlay		4.0 inch overlay	
$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ
75.1	9.5	75.2	8.7	80.7	4.6	75.3	5.1	100	0	100	0

* A 2 inch leveling course was placed prior to the SAMI.

Rubber Membranes for Pavement Encapsulation

Approximately 300 miles of highway are located over expansive soils in northeastern Arizona.[8] The highways are situated within outcrops of the "Chinle Formation" which exhibit considerable volume change due to moisture change in highly expansive soils. The differential movements incurred by pavements overlying these soils results in increased roughness, cracking, and premature failure of the roadway. To address this problem, ADOT constructed its first experimental project utilizing asphalt rubber to form a subgrade seal in 1973. A cut section on U. S. 180, located near the southern boundary of the Petrified Forest National Park, had a catalytically-blown asphalt membrane placed upon the subgrade prior to placement of the select material and asphalt concrete. All three cut-sections utilized paved shoulders to 1 foot up the back slope.

Due to the success of the 1973 experimental section, ADOT continued to pursue the development of the encapsulating membrane seal. However, most of the highways situated within the Chinle Formation had already been constructed and therefore a subgrade seal could only be considered in a reconstruction situation. To solve the problem ADOT elected to construct experimental projects which utilized a membrane seal over the existing pavement and cut ditches. Three projects were constructed between 1975 and 1976, two on Interstate 40 and one on U. S. 89. The first project utilizing the membrane protection extended 11.8 miles along I-40 east of Holbrook.[9] It was constructed adjacent to an 11 mile project constructed one year earlier which did not utilize the membrane protection. The project without membrane protection was considered the control section for comparison with the three experimental membrane projects. The project data and typical sections are shown in Table 6 and Figure 15, respectfully. The details of construction and project evaluations have previously been reported.[8,9,10]

The asphalt rubber on all three experimental sections consisted of 25% vulcanized rubber to 75% AR1000. On the two I-40 projects, the asphalt rubber was applied at 0.65 gallons/yard^2 on the pavement and 0.75 gallons/yard^2 on the earthen shoulders. On the U. S. 89 project the asphalt rubber was applied at 0.65 gallons/yard^2 on the pavement and 0.70 gallons/yard^2 on the earthen shoulders. All the shoulders had an emulsion tack coat (0.08 gallons/yard^2) applied prior to the membrane seal. After the asphalt-rubber seal was constructed, six inches of soil was placed on the shoulders as a protective cover.

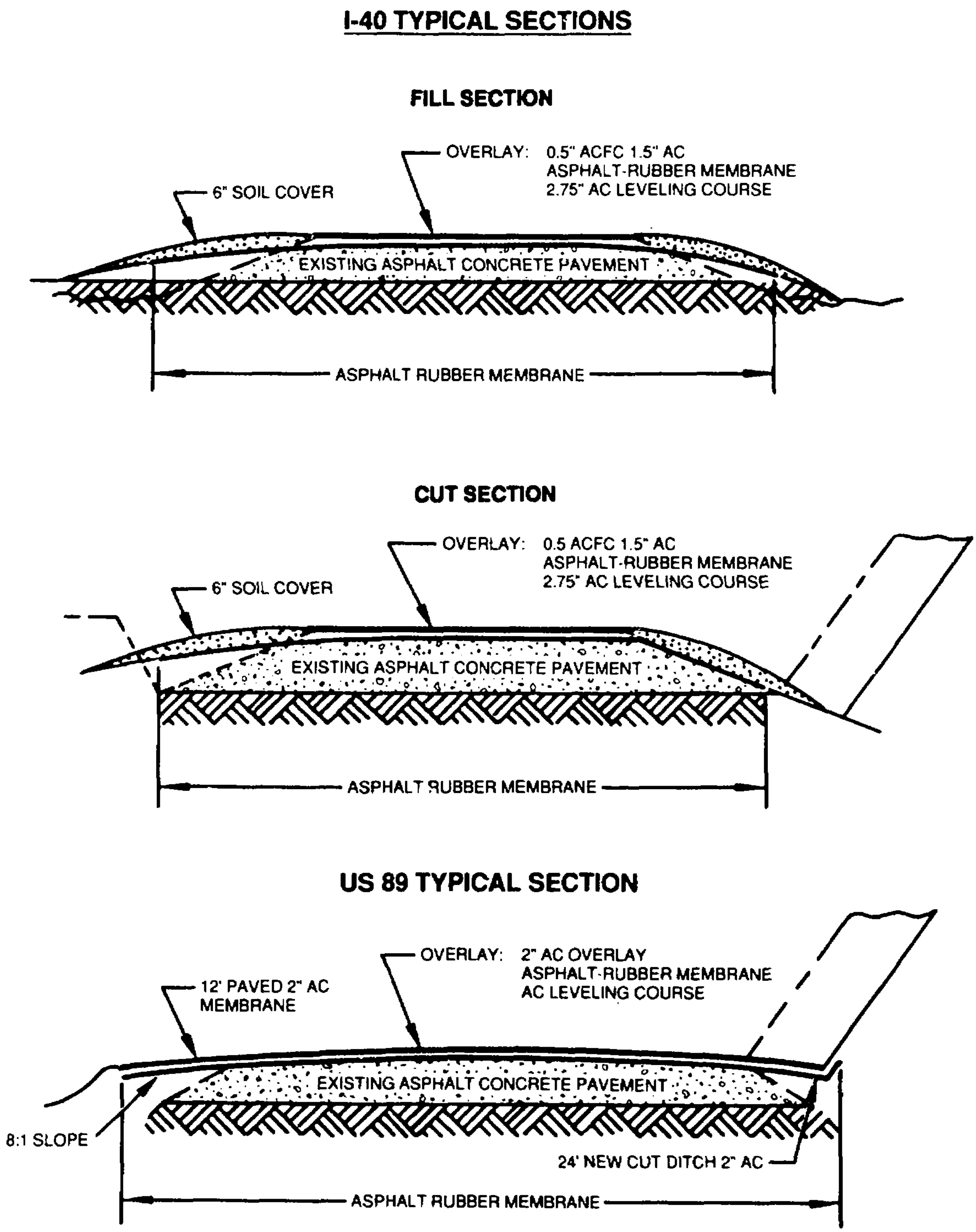

Figure 15 - Typical Sections for Membranes Placed on Pavements

TABLE 6 - PERFORMANCE DATA FOR MEMBRANE PROTECTION SECTIONS

		Rate of Roughness Increase			
Project Number	Year Constructed	$\bar{X}$	σ	C.V.	Range
I-40-5(38)	1974	15.6	3.8	24%	9.6-21.9
I-40-5(44)	1975	9.7	3.2	33%	4.6-16.2
I-40-5(45)	1976	5.5	1.4	26%	3.4- 8.0
F-037-2-502 *	1976	11.1	3.2	29%	7.3-13.1

* Construction Roughness Significantly Different.

In 1979, approximately 3 to 4 years after construction, ADOT reported the results of an on-going evaluation which evaluated changes in roughness, pavement distortion (changes in elevations), cracking, and moisture changes in the subgrade.[8] Several of these previous findings are reproduced here:

(1) "...the untreated sections are showing larger heaves."

(2) "The overall variance would indicate that the membrane seal is working particularly well in the fills and the cut to fill transition."

(3) "The membrane sections in cut and fill show less moisture variance over time than the untreated control sections for all depths except the two foot treated cut."

In addition to these conclusions, the authors produced a table of information shown as Table 7. The original information is shown in normal typeface, while the information displayed in italics is the actual performance data through 1988. It is interesting to compare the actual rate of roughness increase to the previously predicted rate, and the rate experienced prior to the overlay.

Utilizing the previous rate of increase shown in the table, the actual roughness level prior to overlay, and the average actual rate of increase through 1988 (or the service life), the performance can be presented graphically as in Figure 16. It is very obvious that the membrane sections have performed substantially better than the control sections in terms of roughness.

The actual Mays roughness prior to overlaying is indicated on the ordinate axis. The as-constructed roughness is indicated at the zero value of the abscissa. It is evident from this plot that the roughness was typically reduced 200 inches/year by the overlay. The project which utilizes no membrane protection, labeled (38), exhibits a 60% higher average rate of roughness increase than the project constructed adjacent to it, labeled (44). The (44) membrane project also displayed a 30% longer service life than the project with no membrane protection.

It is also evident in Figure 16 that only the (44) project reached 1988 without further rehabilitation. The life of the membrane projects ranged between 7 and 13 or more years while the "control" project lasted 10 years.

Since only the (44) and (38) projects were constructed adjacent to each other, it is of questionable validity to extend the "control" section to projects 35 miles and 160 miles away. When comparing the average rate of increase before membrane placement to the average rate of increase after membrane placement, the beneficial effect of the membranes is very evident. The membranes reduced the rate of roughness increase between 26% and 69%.

If roughness was the only determining factor for the membrane projects, they would have lasted between 14 and 36 years. The dashed lines in Figure 16 indicated the predicted service lives until objectionable roughness would be attained. Obviously, roughness is not the only pavement distress factor.

TABLE 7 - MAYS RIDE ROUGHNESS

PROJECT RIDE HISTORY BEFORE OVERLAY			
Project	Rate of Roughness Increase (inches/mile)	Predicted Years to Objectionable Ride	*Actual Reduction in Roughness Rate During Service Life*
I40-5(38)	15	14	*+ 4%*
I40-5(44)	16	14	*- 39%*
I40-5(45)	18	12	*- 69%*
F-037-2-502	15	15	*- 26%*

OVERLAY PREDICTED ROUGHNESS FROM RIDE HISTORY AFTER OVERLAY					
Project	Rate of Increase (inches/mile)	*Actual Rate of Increase*	Years to Objectionable Ride	*Revised Years to Objectionable Ride*	*Actual Pavement Life (years)*
No Membrane:					
I40-5(38)	14	*15.6*	16	*13*	*10*
With Membrane:					
I40-5(44)	6	*9.7*	36	*23*	*13+*
I40-5(45)	6	*5.5*	36	*36*	*9*
F-037-2-502	6	*11.1*	36	*13**	*7*
	Average	*8.8*		*Average*	*9.7*

* *Construction Roughness Significantly Different*

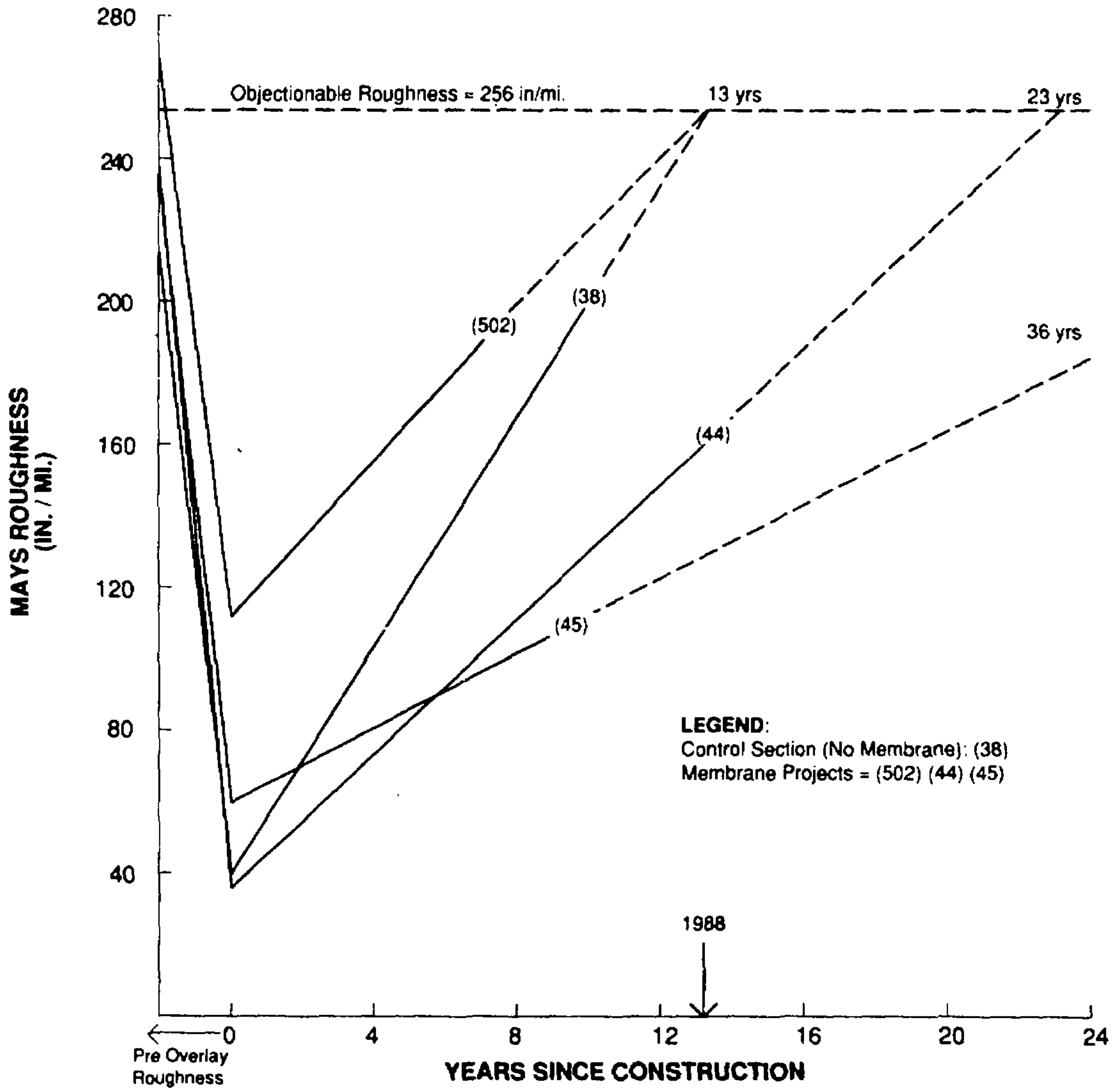

Figure 16 - Mays Roughness With Time

EXPERIMENTAL TEST SECTIONS

Eight experimental projects, containing a total of 47 sections, are reviewed in this paper. The projects were constructed between 1975 and 1986, and represent ADOT's major efforts in the development of asphalt rubber technologies. Many of these sections have reached their terminal service life and the actual performance can therefore be analyzed without the need for "predictions."

Before discussing each of the experimental projects, mention should be made of the historical development of experimental projects in ADOT. Usually only projects which were severely distressed were considered for experimental purposes. The experimental project designs never used replication or randomization, and frequently inadequate pavement distress surveys were performed prior to the experimental treatment. These problems make definite conclusions of field performance difficult.

State Route 87(Beeline Highway)-1975

In 1975, ADOT conducted its most extensive development program in the field of asphalt rubber. During that year, ADOT constructed its first true three layer system, first SAMI beneath an overlay, utilized the ARCO devulcanized process, and constructed its first open graded asphalt concrete utilizing asphalt rubber as a binder. ADOT also constructed one of its most extensive test sections. On State Route 87, locally known as the Beeline Highway, ADOT constructed eleven test sections. Four major pavement treatments were evaluated; open graded asphalt concrete with low percentages of rubber as a mineral filler, three layer system, open graded asphalt concrete with asphalt rubber as a binder, and a section with asphalt modification. In addition to these major experiments, vulcanized and devulcanized rubber sections were constructed for comparison as well as long shard rubber versus granulated rubber as a mineral filler.

The experimental project, constructed between mileposts 193.7 and 205.4, consisted of overlaying the entire 38 foot width of the northbound roadway under construction project F-053-1-926. This section of State Route 87 has incurred approximately 1.2 million 18K ESALS during the 13 years the test sections have been in service. The area receives approximately 10-15 inches of annual rainfall.

The existing pavement consisted of nine inches of select material, two inches of aggregate base, and one inch of bituminous surfacing with several chip seals. It was approximately 20 years old at the time the experimental project was constructed. The northbound roadway consisted of two traffic lanes with two seven foot shoulders. The experimental project consisted of placing ten sections each approximately 1/2 mile in length between MP 193.9 and MP 199.0. The remaining section of project to the north was considered the control section.

The pavement sections, shown in Figure 17, were constructed in 1975 and are still in service after 14 years (1989). A pavement distress survey was conducted in the travel lane using the Corp of Engineers' Paver Method in 1987 prior to rehabilitation.[11] The results of that survey are shown in Table 8. No information is shown for sections D and D_1 because these sections failed in 1979 and were replaced. Section E had extensive patching and sealing which prevented an accurate evaluation. Section I was not evaluated because it appeared to be overlaid at the time of the survey. However, at a later date it was discovered that Section I had had no maintenance.

Rubber As A Mineral Filler Performance Results

From Table 8 it is evident that sections A through E, which represented rubber as a mineral filler, performed the poorest of the four major experiments. Only section C which utilized granulated, devulcanized rubber performed well. The long shard rubber performed substantially worse than the granulated rubber. The devulcanized, granulated rubber performed better than the vulcanized rubber.

Three Layer System Performance Results

The three layer section had the highest average P.C.I. of all the sections and the lowest standard deviation. The high P.C.I. rating and low standard deviation suggests that this section may have significantly better properties as a treatment.

Open Graded AC with Asphalt-Rubber Binder Performance Results

The average P.C.I. of the two sections which make up this experiment are the 2nd and 3rd highest overall. Although the devulcanized rubber had a higher average P.C.I. than the vulcanized section it exhibited greater variability. It appears this design strategy is relatively insensitive to rubber type (i.e. vulcanized or devulcanized).

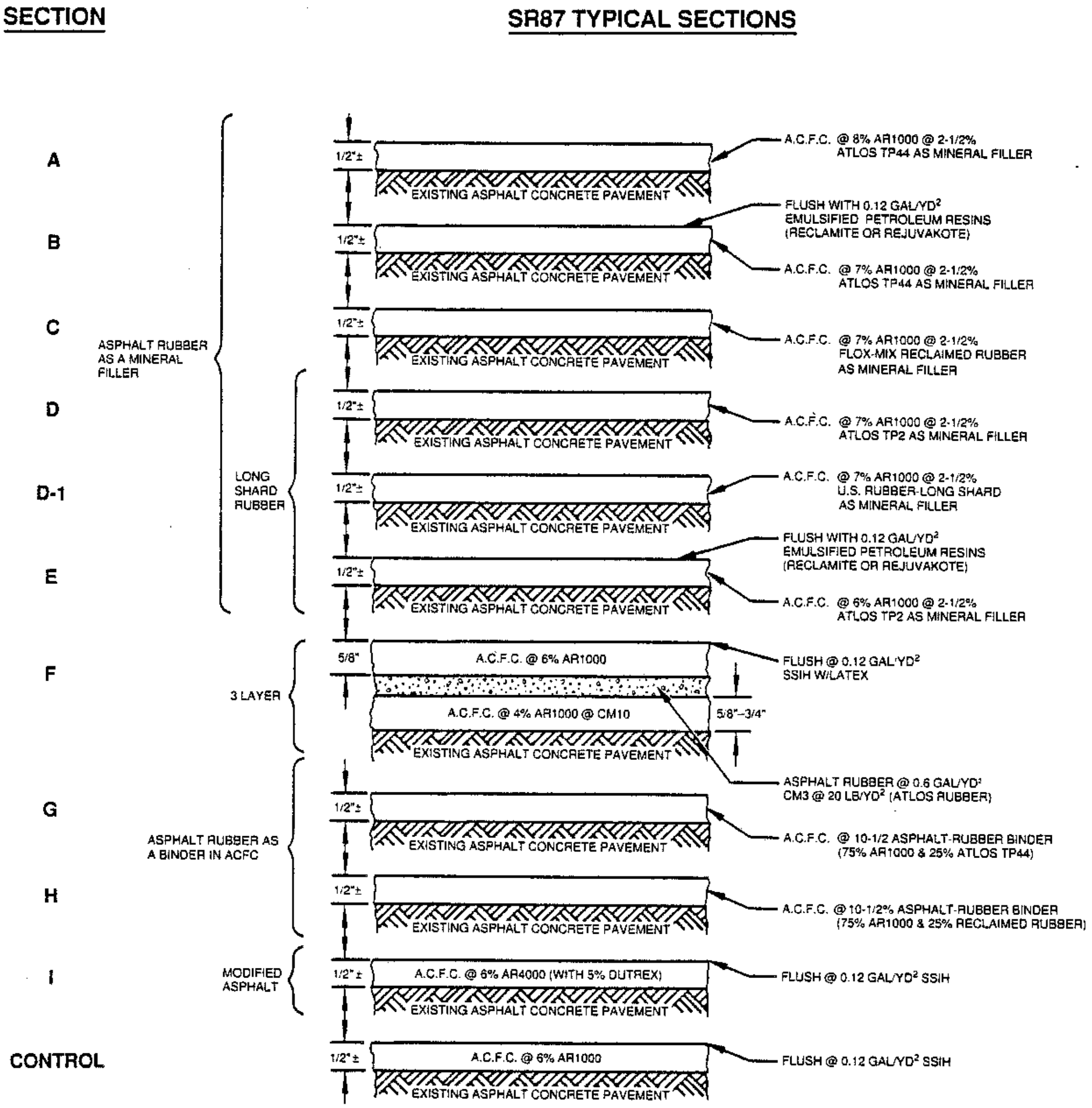

Figure 17 - SR 87 (Beeline Highway) Typical Sections

TABLE 8 - BEELINE HIGHWAY PAVER SURVEY RESULTS[6]

MAJOR EXPERIMENT	Rubber as a Mineral Filler						3-Layer System	Open Graded AC w/AR Binder		No Rubber	
Rubber Type	Granulated Rubber			Long Shard Rubber			Granulated Rubber				
Rubber Composition 1000	Vulcanized Rubber		Devulcanized Rubber		Vulcanized Rubber				Devul. Rubber	6% AR 4000 5% Dutrex	6% AR
SECTION	A	B	C	D_1	D	E	F	G	H	I	CONTROL
Average PCI	43.9	40.1	60.2	N/A	N/A	N/A	61.9	60.9	61.3	N/A	60.1
PCI Std. Dev.	9.4	7.4	3.2	N/A	N/A	N/A	0.5	1.7	3.0	N/A	2.4

Modified Asphalt Performance Results

Although quantitative data is not available on section I, it was reviewed at the same time all the other sections were evaluated. It performed so well that the observers mistakenly thought it had been overlaid. It is the authors' conclusion that this section performed the best of all sections.

Control Section Performance Results

The designated control section performed as well as any other major experiment in terms of average P.C.I.. This section was located beyond an intersection to a recreational area and therefore incurred somewhat less traffic than the other sections.

Cost Comparison

Since the Beeline test sections were constructed as a change order, it provided a unique opportunity to establish relative cost comparisons between the different strategies. Table 9 indicates the cost of construction and the increased cost relative to the control section for each strategy. As evident in the table, Section I, which utilized modified asphalt, was only 8% greater in cost while the three layer system was 185% greater in cost than the control section.

TABLE 9 - TEST SECTION COSTS

SECTION	COST (dollars)	INCREASE IN COST OVER CONTROL SECTION (%)
A	$10,897	55%
B	$11,529	64%
C	$10,475	49%
D	$9,561	36%
D_1	$9,983	42%
E	$10,264	46%
F	$20,036	185%
G	$12,935	84%
H	$10,967	56%
I	$7,593	8%
Control	$7,030	-

I-40 - (East Flagstaff T.I.)-1977

In 1977, ADOT constructed six test sections under project I-40-4-925 between milepost 202.8 and 204. Three major pavement treatments were evaluated for their effectiveness to restore ride quality to a concrete pavement while preventing reflective cracking. Two two-layer systems, three three-layer systems, and a saw and seal section were compared. Each section was approximately 1,000 feet in length and covered the entire 38 feet of the WB roadway. In addition to the three major experiments, vulcanized versus devulcanized rubber, and bottom layer type (i.e. dense graded ac or open graded) were evaluated.

Since construction in 1977, this section of Interstate 40 has incurred approximately 7 million 18K ESALS during its 12 year service life. The area receives approximately 16-20 inches of annual rainfall.

The existing pavement consists of seven inches of subgrade seal, four inches of C.T.B., and eight inches of JPCP. It was approximately 8 years old at the time the experimental projects were constructed. The westbound roadway consists of two 12 ft. travel lanes and a 10 ft. and 4 ft. shoulder.

The pavement sections, shown in Figure 18, were evaluated in 1989. A PAVER distress survey was performed in the travel lane on sections 3 and 6 which were the only sections which had not been overlaid (See Table 10). Sections 4 and 5 failed first and were repaired in 1980. Sections 1 and 2 were repaired at some unknown later date. Section 1 had 100% of the joints reflected through by 1979. Section 1 also only had one of the two designated SAM applications constructed. During construction, it was decided to eliminate the second SAM application after stability problems occurred with the first application.

Based upon the PAVER results, section 3 scored significantly higher than section 6. This was primarily a result of longitudinal cracking at the shoulder joint. Both sections had been sealed and were performing satisfactorily.

Two Layer System Performance

Due to construction problems only one two-layer system was constructed. Unfortunately, it did not survive until the 1989 evaluation and the historical records are too inadequate to accurately assess its performance.

Three Layer System Performance

Both the vulcanized and devulcanized rubber systems placed upon the dense graded asphalt concrete failed within 3 years of construction. The vulcanized rubber system placed upon an asphalt-rubber leveling course provided satisfactory service for 12 years and had the highest average P.C.I.. It should be noted, however, that the passing lane was in significantly worse condition than the travel lane where the PAVER survey was performed.

Saw and Seal Performance

This section has been resealed during its service life and is still performing satisfactorily. Considering the condition of both the travel lane and passing lane, this strategy has performed the best in the author's opinion.

An interesting note is that the saw and seal section and three layer section exhibited significantly higher load transfer across the JPCP joints than the adjoining concrete pavement which had not been overlayed (i.e. 90% versus 35%). Since the concrete pavement was badly D-cracked, it is possible that all these sections reduced moisture infiltration and therefore the severity of D-cracking.

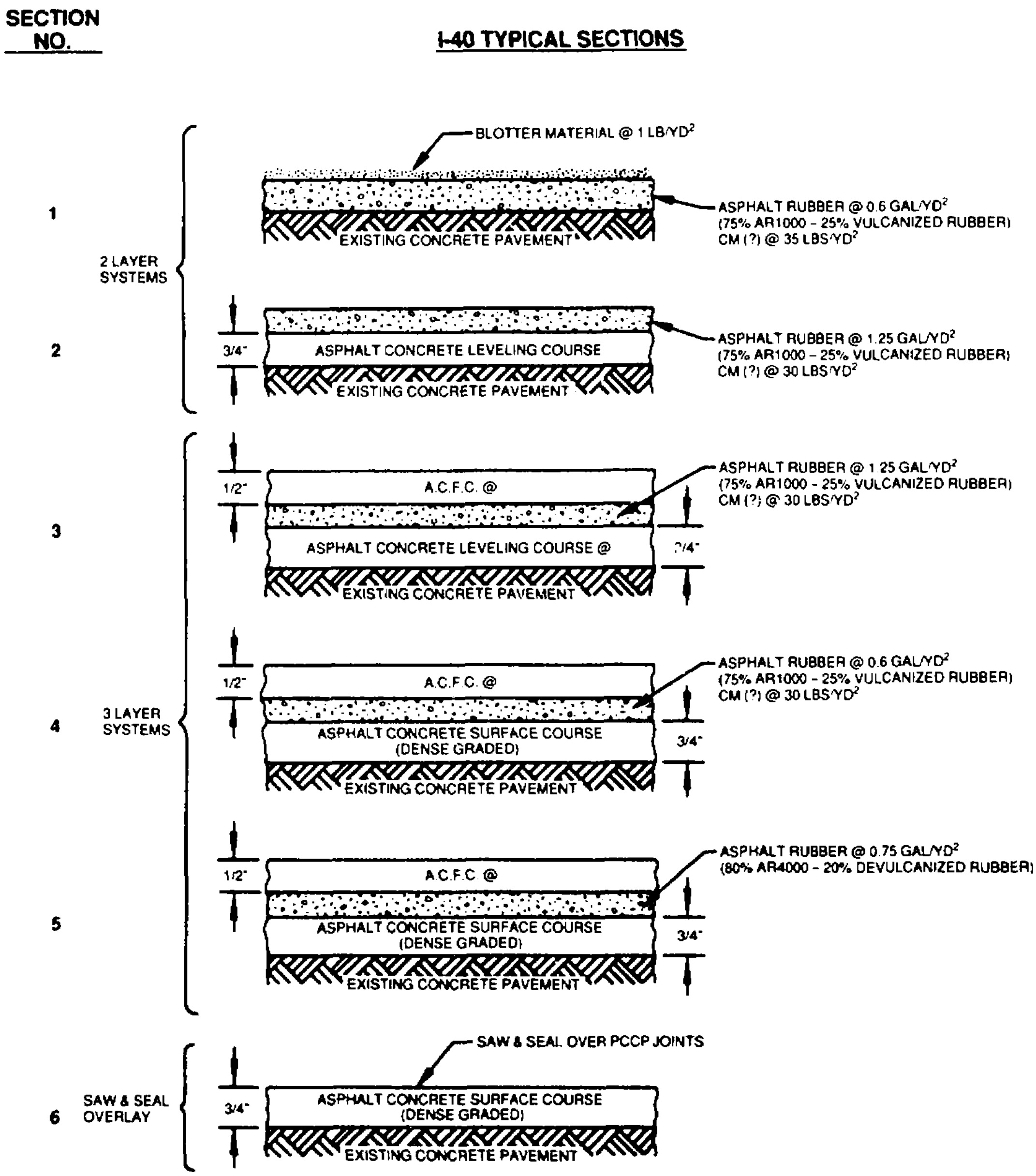

Figure 18 - I-40 (East Flagstaff T.I.) Typical Section

TABLE 10 - I-40 PAVER SURVEY RESULTS

MAJOR EXPERIMENT	TWO LAYER SYSTEMS		THREE LAYER SYSTEMS			SAW & SEAL
Rubber Type	Vulcanized Rubber				Devulcan.	No Rubber
Bottom Layer Type	SAM	ARLC*	ARLC*	ACSC*	ACSC**	ACSC**
Section	1	2	3	4	5	6
Average PCI	-	-	80	-	-	72.9
PCI Standard Deviation	-	-	6.0	-	-	6.7

* ARLC = Asphalt Rubber Leveling Course
* ACSC = Asphalt Concrete Surface Course

I-17 (Munds Park) - 1977

Stripping of a three layer system placed upon a concrete pavement in 1975 produced concern that an asphalt-rubber membrane facilitated stripping of the cover material in high rainfall areas. To investigate this problem, an experimental section was constructed on I-17 between mileposts 313 and 323 near Munds Park. Three experimental sections and a control section were constructed on project I-IR-17-2(78). Three major factors were evaluated; the effect of an asphalt-rubber membrane on the stripping potential, the effect of the aggregate source on the stripping potential, and the effect of the position of the asphalt-rubber membrane in mitigating reflective cracking. Each experimental section and the control section were approximately 1/2 mile in length and extended across the full roadway width of the northbound alignment. Figure 19 indicates the cross-sections for the sections.

The local aggregate source for this project consisted of quarried basalt. This is typical to the Flagstaff and surrounding area and it was the source of concern for the stripping problem. ADOT personnel suspected the basalt aggregate contributed to stripping in asphalt concrete mixtures. To verify this hypothesis, Salt River aggregate from the Phoenix area was hauled over one hundred miles to build one of the test sections. Since the Salt River aggregate was widely used and exhibited minimal stripping potential in the Phoenix area, it was selected for experimentation on the Munds Park project.

To evaluate the effect of the asphalt-rubber membrane location within the pavement structure, an "inverted" SAMI section was constructed. The inverted SAMI section placed the SAMI above the overlay and beneath the ACFC wearing course. The standard practice was to place the SAMI beneath the overlay on the leveling course or existing pavement.

This project received approximately four million 18K ESALs during its eleven year service life. The northbound alignment consisted of two 12-foot travel lanes and a ten and four foot shoulder. The average annual rainfall is approximately 20-25 inches.

A PAVER distress survey was conducted in both the travel and passing lanes in 1988 prior to rehabilitation. The results of this survey and a survey of transverse cracks alone is shown in Tables 11 and 12, respectively. The PAVER survey did not include rutting which would have significantly lowered the results. At a significance level of 0.1, the results of the passing lanes and travel lane are statistically different. Similarly, the control section results were statistically different when compared to the SAMI sections.

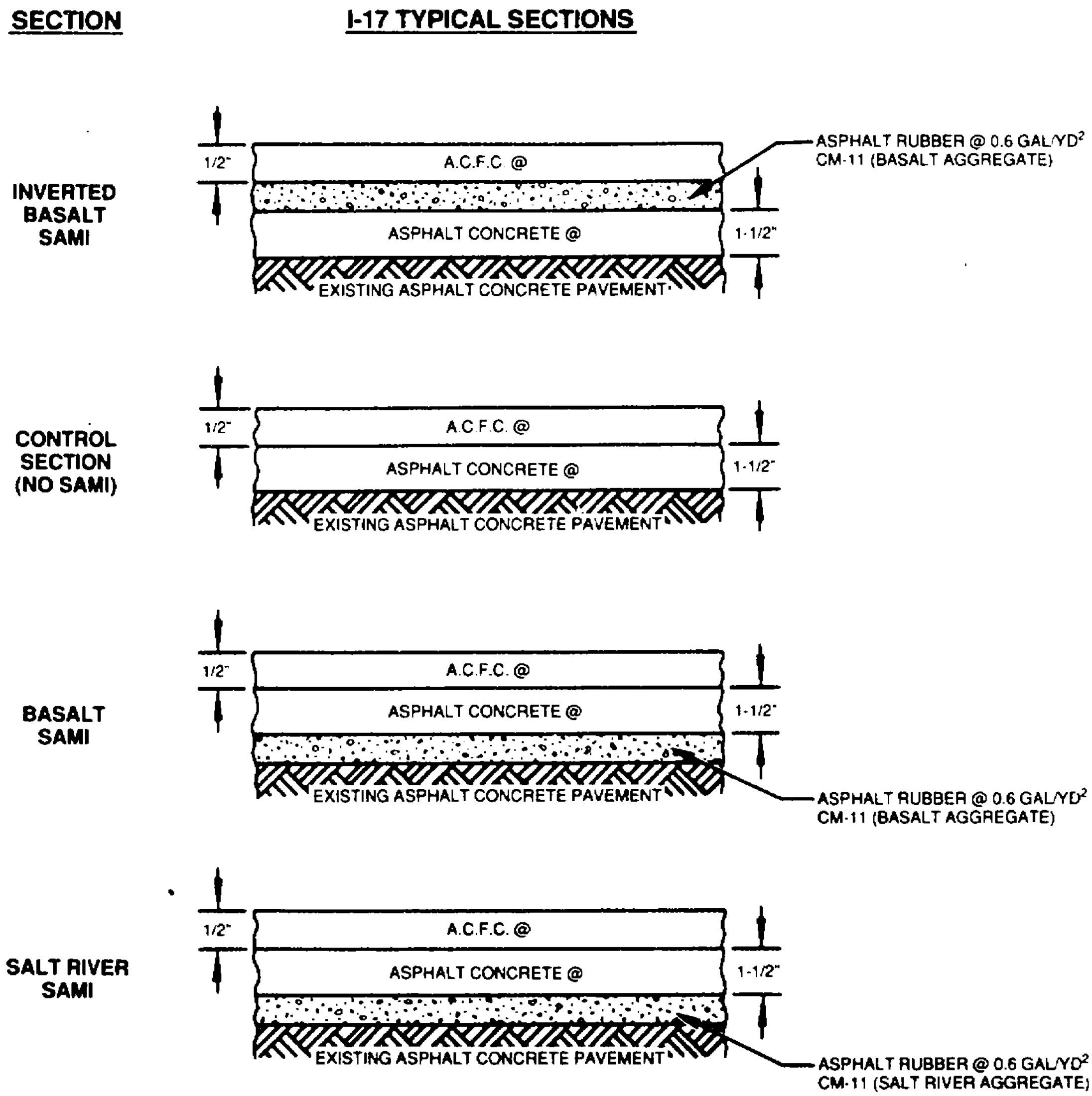

Figure 19 - I-17 (Munds Park) Typical Section

During construction of this project the travel lane was over asphalted due to hot plant problems. This reduces the reliability of the experimental comparisons. Therefore, discussions pertaining to comparisons between the sections are based only on the passing lane P.C.I..

TABLE 11 - MUNDS PARK PAVER SURVEY RESULTS

<table>
<tr><td>MAJOR EXPERIMENT</td><td colspan="8">EFFECT OF AR MEMBRANE ON STRIPPING & REFLECTIVE CRACKING</td></tr>
<tr><td></td><td colspan="4">EFFECT OF AGGREGATE SOURCE ON STRIPPING</td><td colspan="4"></td></tr>
<tr><td></td><td colspan="2"></td><td colspan="4">EFFECT OF AR MEMBRANE LOCATION ON REFLECTIVE CRACKING</td><td colspan="2"></td></tr>
<tr><td>SECTION</td><td colspan="2">SALT RIVER AGG. SAMI</td><td colspan="2">BASALT AGG. SAMI</td><td colspan="2">INVERTED SAMI</td><td colspan="2">CONTROL (NO SAMI)</td></tr>
<tr><td>T=TRAVEL LANE
P=PASSING LANE</td><td>T</td><td>P</td><td>T</td><td>P</td><td>T</td><td>P</td><td>T</td><td>P</td></tr>
<tr><td>AVERAGE P.C.I.</td><td>66</td><td>98</td><td>63</td><td>93</td><td>66</td><td>94</td><td>65</td><td>80</td></tr>
</table>

TABLE 12 - RESULTS OF CRACK SURVEY

Section	Full Width Transverse Cracks (Cracks/Mile)	Quantity of Cracking Lineal Feet (Cracks/Mile)	Quantity of Cracking % of Control
Inverted Basalt SAMI	N.A.	1,824	23%
Control No SAMI	27	7,979	100%
Basalt Aggregate SAMI	2	1,056	13%
Salt River Aggregate SAMI	9	2,303	29%

Effect of Asphalt-Rubber Membrane on Stripping

The results of the pavement distress surveys suggests that the presence of the asphalt-rubber membrane in the SAMI sections did not contribute to stripping. In fact, when the existing overlay was milled out in 1988, field inspections confirmed that this had not occurred.

Effect of Aggregate Source

No apparent differences were evident in the P.C.I. ratings of the Salt River aggregate SAMI and basalt aggregate SAMIs. However, a marked reduction in lineal feet of cracking is evident in Table 12, with the basalt aggregate SAMI exhibiting approximately half the cracking of the Salt River aggregate SAMI. During milling operations, however, no stripping was evident in either overlay.

Effect of SAMI Location on Reflective Cracking

The two basalt SAMIs directly compare the effect of membrane position on the performance of the strategy. The P.C.I. rating shown in Table 11 indicates no significant difference between the sections. Table 12 suggests that the standard SAMI design performed slightly better than the inverted design in regards to reflection cracking. However, when considering the results of the Salt River SAMI, it is questionable whether the results are statistically different. Insufficient data are available to provide statistical inference.

Performance of Test Sections After Rehabilitation

In 1988 the Munds Park test sections were removed as part of a construction rehabilition project. This project consisted of milling off the existing ACFC and 1.5 inch overlay and replacing in-kind. Except for the inverted SAMI section, the SAMIs were not removed and continued to function with the newly placed overlay. The inverted SAMI was milled off with the existing overlay due to its proximity to the ACFC. This produced two sections which no longer had a SAMI beneath the new overlay.

A "windshield" reconnaissance was performed on the test sections in October 1989 approximately one year after construction. The results of this survey are shown in Table 13. The survey recorded only full-width transverse cracks. Since the test sections are of unequal lengths, the results are reported as cracks per mile.

TABLE 13 - RESULTS OF CRACK SURVEY AFTER REHABILITATION

ORIGINAL TEST SECTION	TRANSVERSE CRACKS PER MILE
SALT RIVER SAMI	36
BASALT SAMI	3
CONTROL	91
INVERTED SAMI	72

As evident in the Table, the two sections which still have the SAMI section in place (i.e. Salt River and Basalt SAMIs) exhibit less than half the reflection cracking of the control and inverted sections. These results indicate that a SAMI continues to provide benefit to the pavement structure even after subsequent rehabilitation strategies. It also points out another advantage of placing a SAMI beneath an overlay. On subsequent rehabilitation it will still function even if the existing overlay is milled off.

SR 169 (Dewey-Copper Canyon)-1977

In 1977 ADOT constructed its only test section to evaluate the use of asphalt rubber for construction of an economical low volume road.[12] Eight test sections were constructed under Project F-058-1-501 to compare four major features; performance of a thin overlay to a SAMI with an ACFC, the effect of subgrade stabilization, the effect of a compaction aid, and the effect of an encapsulating membrane.

Figure 20 indicates the pavement sections which were constructed. Unfortunately, during construction borrow material was imported for subgrade construction which possessed greater plasticity than had been designed for. This resulted in many of the sections exhibiting distress within approximately one year of construction. Table 14 reports the results of patch surveys conducted in 1978 and 1980. As indicated in the Table, four of the six SAMI sections exhibited significant distress. In fact, of the eight test sections, only the two sections which utilized subgrade stabilization performed satisfactorily. In 1981 all but the two sections with subgrade stabilization and Section 1 had been overlaid. Section 1 was overlaid in 1985. The remaining two sections were chip sealed by maintenance. In 1989 the two subgrade stabilized sections are still performing satisfactorily, although alligator cracking is evident.

Comparison of Thin Overlay to SAMI With ACFC

No valid comparisons can be made between these strategies because different borrow sources were used for these sections during construction. Since testing of the borrow during construction was not performed, the quality of the subgrade is unknown.

Comparison of Subgrade Treatments

Without a doubt, the two sections with stabilized subgrades out performed all the other sections. The effect of subgrade treatment was the dominant factor in this experiment. As of 1989, no significant difference is discernable between the two stabilized sections. These sections have performed satisfactorily for 12 years with only a chip seal. During this time the project has received approximately 118,000 18K ESALS.

TABLE 14 - DEWEY-COPPER CANYON PAVEMENT SURVEY RESULTS

Experimental Feature	2" AC		Asphalt Rubber SAMI + 1" ACFC					
Subgrade Treatment		Enzymatic Compaction		Cutoff Walls	Stabilization		Borrow	
	AR2000	AR1000			Lime Fly Ash	Cement		
Section	1	8	7	5	2	3	6	4
% of Section Patched in 1978	15.2%	8.5%	6.1%	4.1%	0	0	3.6%	7.9%
% of Section Patched in 1980	20%	93%	78%	13%	0	0	48%	41%

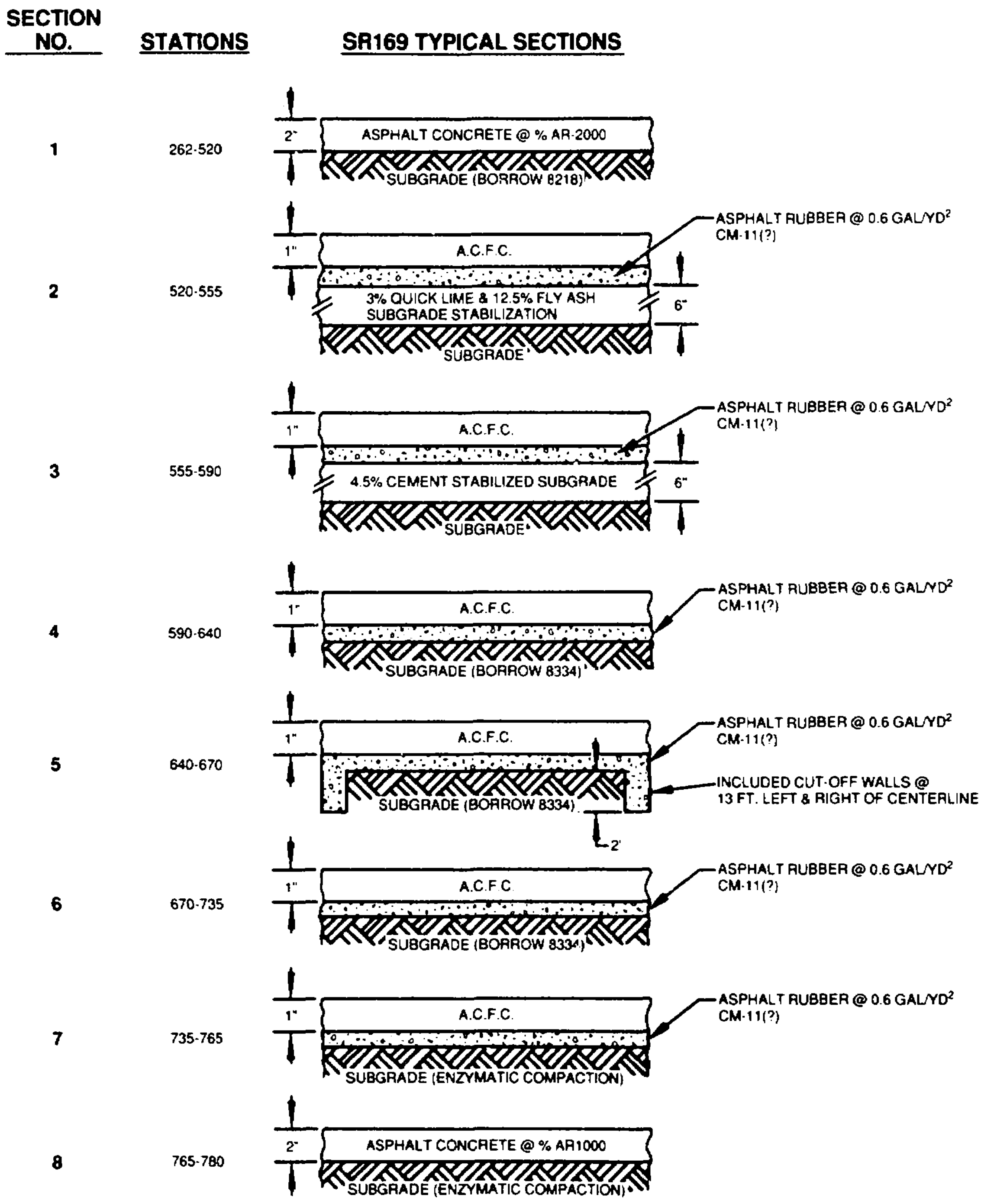

Figure 20 - SR169 (Dewey-Copper Canyon) Typical Sections

SR 85 (Buckeye Liberty) - 1978

In the mid 1970s ADOT began laboratory investigations into asphalt-rubber material properties and behavior. During this same time, the ARCO asphalt-rubber process became competitive with the Sahuaro process. ADOT construction projects were bid with alternate rubber specifications applicable to the ARCO or Sahuaro process. In an effort to coordinate the on-going laboratory asphalt-rubber research with specification development and field performance, ADOT constructed an ambitious asphalt-rubber test section. This project, generally referred to as the Buckeye-Liberty project, was constructed in 1978 on State Route 85 between mileposts 164.4 and 172.0. Fourteen test sections were constructed within the 7.6 mile project. Five different design strategies and three asphalt-rubber materials comprised the major experiment of this project. The five design strategies consisted of SAMIs, three layer systems, thin overlays with ACFC wearing courses, open graded AC mixtures with asphalt-rubber binders, and ACFC wearing courses. In addition to providing multiple comparisons between these strategies, this project provided one of the few direct comparisons between a SAMI and a thin overlay, and an open graded asphalt concrete with asphalt-rubber binder and an ACFC.

Three asphalt-rubber products were utilized on this project; two Sahuaro products and one ARCO product. The ARCO product was their standard material which consisted of 20% devulcanized rubber and 80% AR4000 modified with extender oil. The Sahuaro material was their standard blend which consisted of 25% vulcanized rubber and 75% AR1000 diluted with kerosene, and a modified blend which consisted of 20% vulcanized rubber with 80% AR4000 or AR8000 diluted with kerosene.

State Route 85 in the vicinity of the experimental project has received approximately 1.3 million 18K ESALs during the period 1979 through 1988. The project is located within the desert region at an elevation of 870 feet and receives 7 inches of annual rainfall.

The existing roadway prior to the experimental section consisted of two as-built projects, one in 1947 and one in 1958. The first project constructed a 44 foot roadway between milepost 164.4 and milepost 169 and a 40 foot roadway between milepost 169 and milepost 170.5. Both sections consisted of 9 inches of aggregate base with 2.5 inches of bituminous treated surface. The 1958 project constructed a 40 foot roadway between milepost 170.5 and milepost 172.0 consisting of 12 inches of AB with 2.5 inches of bituminous treated surface.

The pavement sections, shown in Figure 21, were constructed in 1978 and rehabilitated between 1987 and 1988. A PAVER distress survey was performed in the Eastbound travel lane in 1988. The PAVER survey did not include rutting due to traffic control problems. At the time of the survey, Section 8 had been overlaid and many of the sections had extensive patching.

Evaluation Results

Although the Buckeye-Liberty project was ADOT's most ambitious asphalt-rubber test section, it appears that fate and poor experimental design worked together to thwart its success. The experimental sections were placed over two as-built projects which varied in age, section, and width. The project was constructed between October and January when temperatures were often below acceptable levels for proper construction. Coupled with inclement weather which periodically caused construction problems and changes, the design shortcomings precluded obtaining useful experience from this experiment.

Table 15 indicates the results of the PAVER survey performed in 1988 in conjunction with the experimental problems. Unfortunately, extensive patching had been performed by maintenance in 1986 on most of these sections. This undermines the value of the distress survey significantly.

SECTION NO.

SR85 TYPICAL SECTIONS

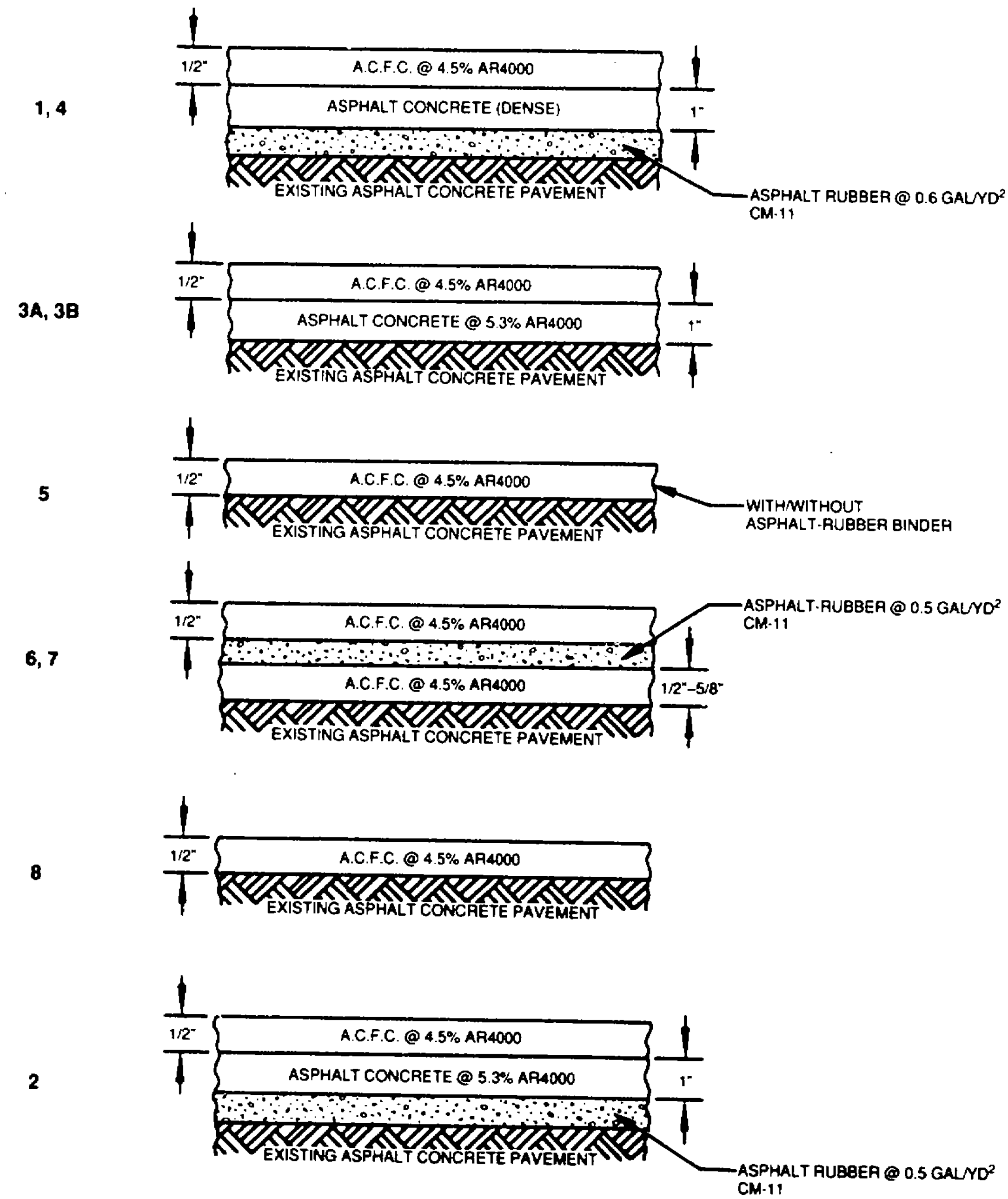

Figure 21 - SR85 (Buckeye-Liberty) Typical Sections

TABLE 15 - BUCKEYE-LIBERTY PAVER RESULTS

DESIGN STRATEGY	SAMI			Three Layer				OG AR ACFC			Thin OL + ACFC		ACFC	
Rubber Type	Vulcanized		Devulcanized			Vulcanized				Devul.	None		None	
CRS-3 Tack	X	X	X					X	X	X	X	X		
MC-250 Tack				X	X	X	X							X
Asbuilt 19__	47	47	47	47	47	47	47	47	47	47	47	47	47	58
Road Width	44'	44'	44'	40'	40'	40'	40'	44'	44'	44'	44'	44'	44'	40'
Month Constr.	Oct		Oct	Dec	Dec	Dec	Dec							Dec
Section No.	1	4	2	6B	7A	6A	7B	5B	5C	5A	3A	3B	5D	8
AVG. P.C.I	10	10	22.9	21	21	N.A.	N.A.	10	45.8	54.4	10	10	10	N.A.

Multiple Comparisons of Design Strategies

The average P.C.I. for each of the design strategies is shown in Table 16. From these data it appears that the SAMI sections, three layer sections, and thin overlays with ACFCs performed similarly. The open graded AR ACFC performed the best.

TABLE 16 - AVERAGE P.C.I. FOR DESIGN STRATEGIES

SAMI	Thin Overlay and ACFC	Three Layer System	OGAR ACFC	ACFC
14.3	20	21	36.7	10

Comparison of the Asphalt-Rubber Materials

The original experiment attempted to evaluate the performance of vulcanized and devulcanized rubber systems commonly used in the industry as well as an optional vulcanized system utilizing the same rubber percentage and grade of asphalt commonly used in the devulcanized system.

At the time of the 1988 survey it was not possible to attest to any differences between the performance of the asphalt-rubber materials.

Construction Effects and Experimental Design

The author believes that the problems in construction and the lack of rigorous experimental design precludes definitive conclusions on this project. The only conclusive statement is that all the sections carried heavy truck traffic for eight years without rehabilitation. The original as-built project was 41 years old in 1988 and had only 3 inches of surfacing material on 9 inches of AB in some areas.

I-17 (Durango Curve-16th Street)-1979,1985

1979 Durango Curve Section

Two three layer systems have been placed on I-17 to restore ride to the concrete pavement and prevent reflection cracking. The first experiment consisted of a 1500 ft. section placed on the eastbound roadway of I-17 at the Durango curve. This section of I-17 is on a superelevated curve and incurred approximately 82,000 ADT at the time of the three layer placement.

The project was initiated to verify the performance of the three layer system under extreme traffic conditions. The three layer system had been developed by ADOT as a rehabilitation strategy for its 20 year old urban concrete freeway. Only vulcanized rubber was used and the mixture proportioned 25% rubber to 75% AR2000.

The section performed satisfactorily from 1979 to 1985 when 1000 feet were removed and replaced with a subsequent three layer section. During the six years of service life the pavement received approximately 11.5 million 18K ESALS. Reflection cracking was first observed after approximately five years, at the transverse joints.[13] The reflection cracking at the transverse joints became progressively worse with time.

Both three layer projects are located within the Phoenix Metropolitan area. They receive 6-7 inches of annual rainfall.

1985 16th Street Section

The second three layer system was placed on the eastbound and westbound roadways contiguous with the location of the previous project. This project utilized the three layer system as the first "routine" rehabilitation strategy for concrete pavement. This section did, however, contain a 1500 ft. experimental section which utilized devulcanized rubber proportioned 20% rubber to 80% AR2000.

During construction of the 1985 three layer section considerable windshield damage occurred while traffic travelled over the CM-11 chips placed in the interlayer prior to placement of the second ACFC. This problem resulted in the Department reducing the "cure time" on the asphalt-rubber membrane from 72 hours to placing the top ACFC as soon as possible. Originally, a 72 hour cure time was required to allow the kerosene sufficient time to evaporate. Under heavy traffic conditions and high speeds (45MPH), windshield damage resulted.

The 1985 three layer system has performed satisfactorily to date. It reduced Mays roughness 200 inches per mile and has received approximately 7 million 18K ESALS. Reflection cracking was first observed at the transverse joints approximately three years after construction. In 1988 4 inch diameter cores were removed from the three layer section to expose a longitudinal and transverse joint in the underlying JPCP. The longitudinal joint was 1/2" to 1" wide while the transverse joint was 1/2" to 5/8" wide. In 1989 crack sealing operations were performed on most of the eastbound roadway and sections of the westbound roadway. Aside form the crack sealing operation, this pavement is still performing well.

I-19 - 1988

Due to chip retention problems experienced on the 1985 three layer installation, ADOT developed a new system for restoring ride to plain jointed concrete pavements. This application consisted of an open-graded asphalt concrete with asphalt-rubber binder. Its first use was on concrete pavement on I-19 just south of Nogales, Arizona. One and one half miles of the southbound roadway were overlaid with a one inch surface course. Since it is a plant mixture, the application is constructed in a manner similar to conventional asphalt concrete. The experimental section was constructed without problems and has performed satisfactorily for over one year.

CURRENT DEVELOPMENT

Asphalt Rubber as a Binder in Asphalt Concrete

The utilization of asphalt rubber as a binder in asphalt concrete began in 1975 with the placement of two test sections on State Route 87. These sections utilized 10.5% total binder content and were placed approximately 1/2 inch in thickness. The binder consisted of 75%AR1000 and 25% rubber. Both vulcanized and reclaimed rubber were utilized.

Currently ADOT utilizes two designs with asphalt rubber as a binder. The first is an ACFC with approximately 8% total binder content consisting of 80% AC10 and 20% vulcanized rubber. This material is placed as a one inch overlay on both flexible and rigid pavements. The second design is a dense graded mixture which utilizes approximately 6% total binder content consisting of 80% AC10 and 20% vulcanized rubber. The gradations for each of these mixtures are shown in Table 17. The open graded mixture is typically placed 3/4" to 1" in thickness while the dense graded mixture is typically placed 1.5" to 2" in thickness. These mixes have only been utilized since 1987 and are experiencing increased use.

TABLE 17 - AGGREGATE GRADATIONS FOR ASPHALT RUBBER MIXTURES

OPEN GRADED ARAC		DENSE GRADED ARAC	
Sieve Size	% Passing	Sieve Size	% Passing
3/8"	100%	1/2"	100%
#4	30-60%	3/8"	80-90%
#8	6-10%	1/4"	40-60%
#200	0-2.5%	#8	20-30%
		#40	5-15%
		#200	0-2.5%

RESULTS

Over the past two decades ADOT has evolved from using slurry applied asphalt-rubber chip seals to an open graded asphalt concrete utilizing asphalt-rubber binder. Ninety percent of the asphalt rubber use has been to mitigate reflection cracking through the utilization of SAMs and SAMIs. These design strategies reached their peak use between 1975 and 1977 and then gradually declined in use until 1980 - 1981 when each strategy had virtually no use. The SAMI strategy has gradually increased in use since 1981 but is still only about 11% of its peak use in 1976. SAM applications appear to not have been used since 1982. Apparently, asphalt-rubber ACFCs have replaced the SAM strategy, although only limited use of AR-ACFC has occurred.

Approximately 10% of ADOT's system has utilized asphalt rubber in some form. Although a significant decline in its use occurred in the beginning of this decade, projects incorporating asphalt rubber continue to provide additional benefit even after they have been rehabilitated. ADOT typically leaves the asphalt-rubber material in place when rehabilitating and places additional pavement courses above it. This compound use makes it difficult to evaluate the life cycle value of the strategy.

SAMI treatments have demonstrated at a network level and on experimental projects that they mitigate the effects of reflection cracking. However, the service life of a SAMI on ADOT's system is not a function of crack distress alone. Other forms of distress such as roughness, bleeding, etc. may determine the in-service life of the treatment.

Although only a limited investigation was attempted, it appears that inadequate information is available to determine the reasons for rehabilitation of these strategies on the ADOT system. One thing is clear, however, the level of cracking on these projects was not adequate to trigger the rehabilitations at the time of occurrence.

ADOT's PMS database assesses pavement cracking as the percentage of total cracking within a given area. It does not distinguish between the different types of cracking such as longitudinal, transverse, alligator etc., or the severity of these distresses. It is therefore difficult to determine where an asphalt-rubber membrane would perform most successfully. For example, previous research has suggested that the block size of cracking can be correlated with the crack movement and pavement structure.[14] This infers that the performance of the overlay strategy is affected by the type and size of cracking. If this information was available for the sections in the PMS database it may then be possible to explain the 30%-45% variation in pavement service life for the SAM and SAMI sections.

ADOT's current philosophy is to utilize reacted asphalt rubber as a binder in open graded and dense graded asphalt concrete. These treatments are utilized for overlaying rigid and flexible pavements and are typically placed in one inch and 1.5 to 2 inch compacted thicknesses for the open graded and dense graded mixtures, respectively.

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APPENDIX 1

YEAR	ITEM NO.	DEVELOPMENT	ROADWAY
1964	1	McDonald "band aid" Repair Applied	U.S. 666
1967	2	Experimental SAM	SR 87
1968		Slurry Applied SAM	U.S. 60
		Distributor Applied SAM	I-17 (Frontage Road)
1969			
1970			
1971		SAMI Application Above Overlay	I-40
1972		Kerosene Dilution of AR Mixture	U.S. 60 SR 71
1973		AR Membrane Seal of Subgrade	SR 180
	3	Major AR Treatment in Northern Arizona	U.S. 89
1974		AR Crack Sealing	U.S. 89A
1975		Three Layer System on HMAC Pavement	SR 87
		AR Open Graded AC Mixture	SR 87
		Sahuaro versus ARCO Applications Comparisons	SR 87
		Rubber as a Mineral Filler	SR 87
	4	Three Layer System on Concrete Pavement	I-40
	5,6	Encapsulating AR Membrane Seal Over Existing Pavement and Shoulder	I-40
		ADOT Implemented the Use of SAMI as SOP for Overlays <4" where cracking is a concern	
		ARCO Application Technique Became Available	
		SAMI Placed Beneath Overlay	I-40
1985		Devulcanized Rubber Three Layer	I-17
1986		AR Open Graded AC Mixture	I-40 (detour)
1988		AR Open Graded AC Overlay on Concrete	I-19